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Institute of Polar Studies

Report No. 54

Late Quaternary Environmental History of the Tanana Valley, Alaska

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Thomas A. Ager

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ABSTRACT

Pollen histories from three lakes and a peat bog in the middle Tanana Valley, interior Alaska, provide a regionally-consistent record of vegetational changes spanning approximately the last 16,000 years. Lacustrine sediment cores from Birch Lake ($64^\circ 19'$ N Lat., $146^\circ 40'$ W Long.) and Lake George ($63^\circ 47'$ N Lat., $144^\circ 30'$ W Long.) yielded the oldest pollen records yet obtained from interior Alaskan lakes. Pollen spectra from the basal sections of these cores are assigned to Pollen Zone 1, and they are characterized by high percentages (20-50%) of both grass and sage (Artemisia) pollen, and lower but significant amounts of sedge and willow pollen. Zone 1 pollen spectra contain only a few percent of pollen of spruce, birch, and alder. The vegetation that produced Zone 1 pollen spectra was a steppe-tundra which probably covered the Tanana Lowland and much of the adjacent Yukon-Tanana Upland during full glacial conditions of the late Wisconsin, until about 14,000 radiocarbon years ago. Inferred climate during the time of steppe-tundra was significantly drier than at present, with a mean annual temperature at least several degrees colder than the present figure of $-4^\circ C$. Increased continentality probably resulted in warm, dry summers of short duration, and long severe winters.

Pollen Zone 2 persisted from about 14,000 years ago until about 10,000 years ago. Zone 2 pollen spectra are characterized by very high percentages of dwarf birch pollen and lower but significant percentages of grass, sedge, and willow pollen. Zone 2 vegetation was a form of shrub tundra. The transition from Zone 1 to Zone 2 appears to have been abrupt and may reflect a sudden climatic change to warmer and moister conditions about 14,000 years ago. Absolute Pollen Influx data (API) show at least a 3-fold increase in the rate of pollen deposition in Zone 2 time over Zone 1 time.

Pollen Zone 3 is subdivided into Subzones 3A and 3B. Subzone 3A records the invasion of spruce into the region, beginning roughly 10,000 years ago. Most of the pollen histories from the region show a rather abrupt initial increase in spruce pollen percentages. The Birch Lake Core II record displays a more gradual initial increase however, which suggests that spruce trees did not actually reach the vicinity of Birch Lake, and perhaps the Fairbanks area, until about 9000 years B.P. The invasion of spruce probably proceeded along rivers initially, forming gallery forests surrounded by shrub tundra. By about 9000 years B.P. forests were evidently well-established in much of the region. The spruce invasion suggests a further climatic warming, but the radiocarbon chronology is not yet sufficiently detailed to pinpoint the time of initial increase in spruce pollen in the cores. Therefore, it is uncertain whether the invading spruce arrived from some distant refugium

many years after the climate had become suitable in interior Alaska, or a few scattered spruce did survive in or near the Tanana Valley during the late Wisconsin glaciation and expanded their range immediately when climatic conditions allowed.

Subzone 3B spans the past 8400 years. The boundary between Subzones 3A and 3B is marked by an increase in alder percentages and the onset of a decline in spruce pollen percentages. Spruce pollen percentages and API continued to decline until about 7000 years B.P., perhaps as an indirect result of an interval of warmer, drier climate. Lowland vegetation of the region has undergone no significant change during the past 6500 years insofar as can be discerned from the pollen record.

ACKNOWLEDGMENTS

My initial interest in undertaking this research arose from stimulating discussions with Professor R.D. Guthrie at the University of Alaska and correspondence with Dr. John V. Matthews, Jr., now with the Geological Survey of Canada. Actual initiation of the project would have been impossible without the encouragement and assistance of Professors Richard P. Goldthwait and Paul A. Colinvaux, of The Ohio State University.

Support for the 1972 field season was provided by a grant-in-aid from the Society of the Sigma Xi and by grants and equipment provided by the Institute of Polar Studies, the Department of Geology and Mineralogy, and the Friends of Orton Hall Fund, all of The Ohio State University. Mr. Thomas Goldthwait generously contributed the use of his vehicle in Alaska during the field season.

Most of the field work was done in the summer of 1973. Support for that field season and for the subsequent laboratory analysis of cores was provided by National Science Foundation Grant DES 73-06503-A01 awarded to Dr. Richard P. Goldthwait, principal investigator.

Dr. Goldthwait contributed generously of his time and effort in all stages of the project and supervised the analysis of cores of lacustrine sediments in the Quaternary Laboratory of the Department of Geology and Mineralogy.

Dr. Paul A. Colinvaux, Department of Zoology, provided coring equipment, extensive use of laboratory space and equipment, and devoted many hours to instructing and guiding me in the techniques of pollen analysis. His willingness to discuss implications and interpretations of the research, as it developed, was most useful and stimulating.

Many other individuals assisted in various field and laboratory phases of this research project. Among those who merit special acknowledgment is Mr. Steven Buttrick, botanist, presently at the University of British Columbia. Mr. Buttrick assisted during the 1973 field season in both the coring operations and collecting and identifying vascular plants. Mssrs. Stephen Derksen, Steve Jacobson, and John Muskopf, under the supervision of Dr. R.P. Goldthwait, performed most of the sediment grain-size analyses. Professor Willard C. Myser instructed me in the use of the industrial x-ray unit. Ms. Denise Fogle, Ms. Kathy Strong, and Mr. James Murtha spent many hours in the laboratory preparing much of the modern pollen reference collection. Most of the pollen reference material was made from herbarium specimens collected during the 1973 season.

Additional material was obtained from the polar plant collection of The Ohio State University Herbarium. I am grateful to the staff of the Herbarium for permitting the use of herbarium material for this purpose. Most of the pollen diagrams and other figures were drafted by Mr. Don Keller and Mr. Frank Holterhoff.

This manuscript has been critically reviewed by Professors R.P. Goldthwait, P.A. Colinvaux, G.E. Moore, and G.D. McKenzie. Mr. Peter J. Anderson edited the manuscript and prepared it for publication. Mrs. Jean Cothran typed the publication manuscript.

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LIST OF PLANT NAMES FREQUENTLY USED IN THIS REPORT

Taxonomic nomenclature follows that of Hultén (1968)

Common Name	Scientific Name
white spruce	*Picea glauca* (Moench) Voss
black spruce	*Picea mariana* (Mill.) B.S.P.
larch (or tamarack)	*Larix laricina* (DuRoi) K. Koch
lodgepole pine	*Pinus contorta* Dougl.
paper birch	*Betula papyrifera* Marsh.
alder	*Alnus crispa* (Ait.) Pursh
	Alnus incana (L.) Moench
quaking aspen	*Populus tremuloides* Michx.
balsam poplar	*Populus balsamifera* L.
willow	*Salix* spp.*
dwarf birch	*Betula nana* L.
shrub or resin birch	*Betula glandulosa* Michx.
heath	Ericaceae
grass	Gramineae
sedge	Cyperaceae

*According to species range maps in Hultén(1968) and Viereck and Little (1972), about 24 *Salix* species may occur within the area shown by Figure 2 of this report. A recent revision of the genus *Salix* for the Alaska-Yukon Territory (Argus, 1973) suggests a slightly higher number of species within the study area.

INTRODUCTION

Nearly all of the vast region of interior Alaska that lies between the Brooks Range to the north and the Alaska Range to the south was unglaciated even during the most severe climatic episodes of the Quaternary. The major mountain ranges of Alaska were extensively glaciated several times during the Quaternary (Fig. 1), yet only scattered high peaks within the "ice-free" corridor developed cirque and valley glaciers of local extent (e.g. Péwé et al., 1967). Eustatic lowering of sea level during major Quaternary glaciations exposed the Bering Land Bridge connecting eastern Siberia and western Alaska (Hopkins, 1967). This broad intercontinental corridor has great biogeographical significance. It accounts for the distribution of many elements of modern and fossil faunas and floras, particularly in northern North America and Siberia (e.g. Vangengeim, 1967; Flerow, 1967; Hultén, 1937). The Bering Land Bridge was the probable route for migrations of early man into North America from eastern Asia (Müller-Beck, 1967).

Hulten's studies of the distribution of vascular plants in northwestern North America and Siberia (1937) led him to recognize the importance of the unglaciated corridor as a refugium in which many species of plants survived the Quaternary glaciations. At the end of the late Wisconsin (and earlier glaciations), the plants of the refugia spread into new habitats exposed as ice receded.

The Quaternary history of vegetation within the ice-free corridor is far from complete, however. The technique of pollen and spore analysis has been used with great success in Europe, North America, and elsewhere (e.g. Faegri and Iversen, 1964; Wright 1971). As yet, few localities within the ice-free refugium of Alaska have been studied by pollen analysts. Several important studies have been made in western Alaska (e.g. Colinvaux, 1964, 1967a; Matthews, 1974b) and in northwestern Canada (e.g. Rampton, 1971a; Terasmae and Hughes, 1966; Lichti-Federovich, 1973, 1974). Data from interior Alaska are particularly scanty; the most important previous pollen work there was done recently by Matthews (1970, 1974a).

The major objective of this study was to provide the most detailed vegetational history yet obtained from interior Alaska. To achieve this goal, several lakes in the Tanana Valley were cored for the first time. Six sediment cores thus obtained were used for pollen analysis, radiocarbon dating, and sediment grain-size analysis. The resulting data permit reconstruction of vegetational history spanning the past 16,000

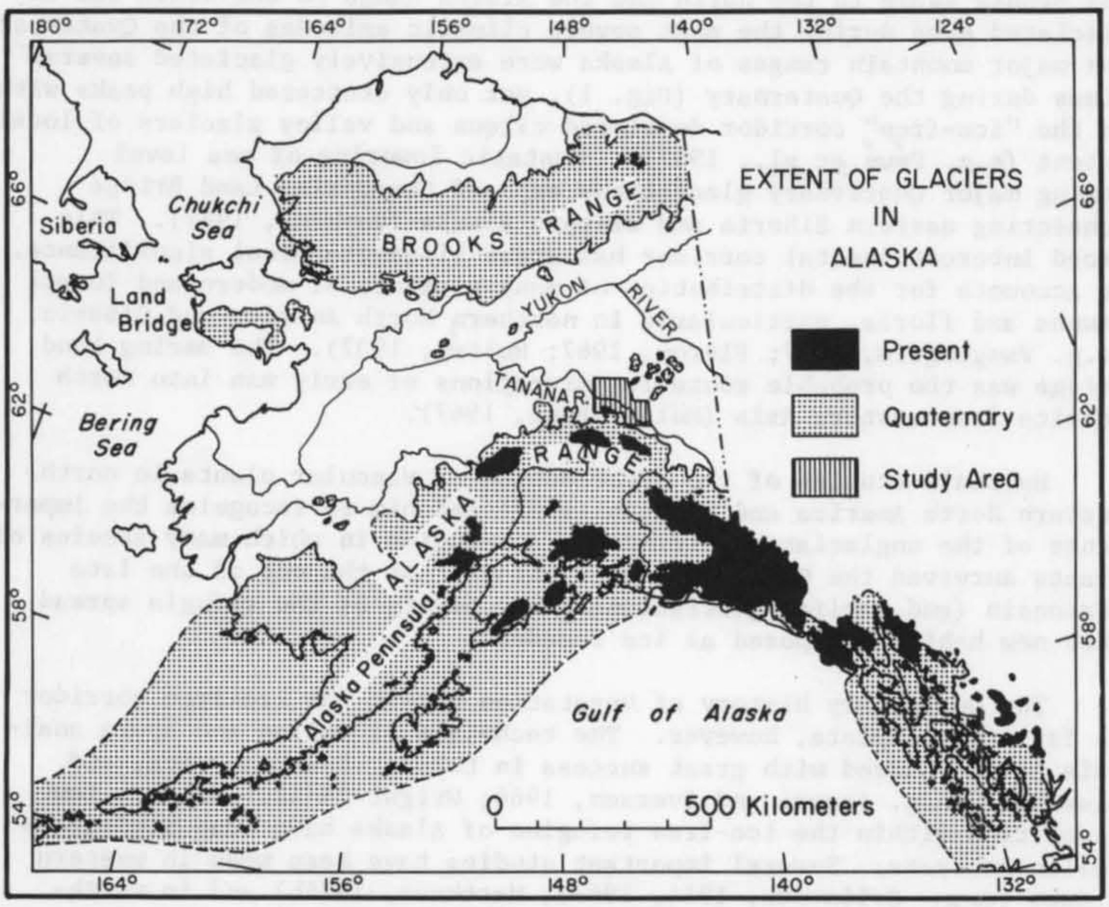

Fig. 1. Extent of glaciation in Alaska during the Quaternary. Map modified from Coulter et al. (1965) and Péwé et al. (1965).

years and provide a basis for inferring climatic changes over that interval. The data also provide the history of lake formation in at least two localities. The pollen records obtained from Tanana Valley lakes differ somewhat from those obtained from the frozen colluvium of the Yukon-Tanana Upland by Matthews (1970, 1974a).

Physiographic Setting

The physiographic setting of the study area (Figs. 1 and 2) has been described by Péwé (1965) and Wahrhaftig (1965). The region shown in Figure 2 includes portions of three major physiographic provinces of Alaska. These are, from north to south, the Yukon-Tanana Upland, the Tanana Lowland, and the eastern part of the Alaska Range. The sediments cored during this investigation are from lakes that lie along the boundary between the Tanana Lowland and the Yukon-Tanana Upland (Fig. 2).

The Tanana River flows along the northern edge of the Tanana Lowland, its course deflected northward by vast merging outwash fans built out from the northern foothills of the Alaska Range. The Tanana River is one of the major trunk streams of interior Alaska. It merges with the Yukon River west of Fairbanks. That portion of the Tanana Valley between Fairbanks and Lake George is referred to in this report as the middle Tanana Valley. The altitude of the Tanana River at Fairbanks is about 140 meters; in the vicinity of Lake George, to the southeast, it is about 400 meters.

The Alaska Range has rugged glaciated peaks that rise to altitudes of more than 2800 meters. Several major rivers, including the Delta River, the Gerstle River, and the Johnson River flow into the Tanana River from glaciated headwaters in the Alaska Range.

The Yukon-Tanana Upland displays more subdued topography than does the Alaska Range; only a few peaks in the Upland attain altitudes in excess of 1800 meters. No glaciers now exist in the Yukon-Tanana Upland. The tributaries draining the Upland contribute much less water and sediment to the Tanana River system than those derived from the Alaska Range. The most widespread formation in the Yukon-Tanana Upland and in much of the eastern Alaska Range is Birch Creek Schist, believed to be of Precambrian age. The schist was extensively intruded by granitic stocks during the Mesozoic (Holmes and Foster, 1968). This schist and granitic bedrock occurs in the vicinity of all the lakes cored in the middle Tanana Valley. Most of the bedrock in the southern Yukon-Tanana Upland is mantled with Quaternary eolian sediments and colluvium.

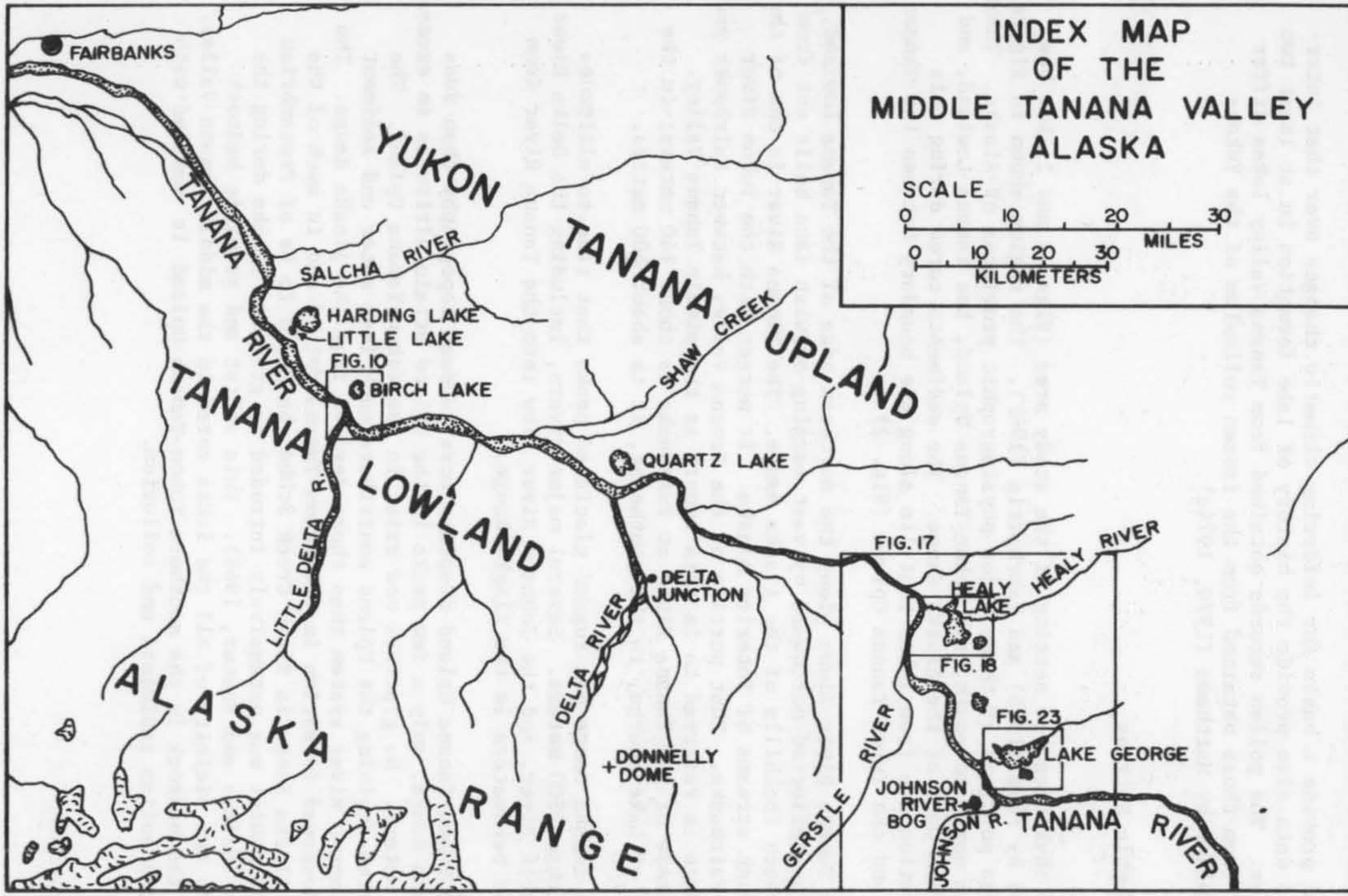

Fig. 2. Index map of Middle Tanana Valley, Alaska.

Climate of the middle Tanana Valley

This discussion of the climate of the middle Tanana Valley is based upon publications by Johnson and Hartman (1969) and Streten (1969, 1974). The Tanana Valley lies within the zone of continental climate which extends over most of interior Alaska. The mountain barriers to the south limit the influence of warmer, moist air from the North Pacific upon the climate of the interior. Annual precipitation is low, only about 30 cm in the lowlands. The Tanana Valley is a region of extreme temperature variations, with winter temperatures sometimes falling below -45°C and summer temperatures occasionally exceeding 32°C.

Coldest mean winter temperatures occur in valley bottoms, over which strong, persistent temperature inversions frequently form. Mean January temperature is about -22°C with mean January maximum and minimum temperatures about -17.8°C and -26.7°C. Snowfall in the lowland areas is about 125 cm per year. In winter it is generally calm near Fairbanks, but severe winds are common in the vicinity of the Alaska Range. Duration of sunlight in late December is 4 hours per day.

Spring breakup usually occurs in mid-May, although ice cover of some lakes may persist until well into June (Swartz, 1966). Mean July maximum and minimum temperatures are about 21°C and 10°C, and mean July temperature is 15.5°C. Maximum duration of sunlight is 22 hours per day in late June. Most of the mean annual precipitation falls as rain in late July and August.

The mean annual temperature is approximately -4°C. The region is underlain by discontinuous permafrost which occurs generally in valley bottoms, particularly where there is fine-grained sediment and a thick vegetation mat. North-facing slopes are also underlain by permafrost, but south-facing slopes are generally free of it (Péwé, 1965).

Climate of the middle Tanana Valley

This discussion of the climate of the middle Tanana Valley is based upon publications by Johnson and Hartman (1969) and Simpson (1967, 1970). The Tanana Valley lies within the zone of continental climate which extends over much of Interior Alaska. The mountain barriers to the south limit the influence of maritime, moist air from the North Pacific upon the climate of the interior. Annual precipitation is low, only about 30 cm in the lowlands. The Tanana Valley is a region of extreme temperature fluctuations, with winter temperatures sometimes falling below -50°C and summer temperatures occasionally exceeding 32°C.

Coldest mean winter temperatures occur in valley bottoms, over which strong, persistent temperature inversions frequently form. Mean January temperature is about -23°C with mean January maximum and minimum temperatures about -17.8°C and -28.7°C. Snowfall in the lowland areas is about 127 cm per year. In winter it is generally calm near Fairbanks, but strong winds are common in the vicinity of the Alaska Range. Duration of sunlight in late December is 4 hours per day.

Spring breakup usually occurs in mid-May, although ice cover of some lakes may persist until late June (Rogers, 1960). Mean July maximum and minimum temperatures are about 22°C and 10°C, and mean July temperature is 15.5°C. Maximum duration of sunlight is 22 hours per day in late June. Most of the mean annual precipitation falls as rain in late July and August.

The mean annual temperature is approximately -4°C. The region is underlain by discontinuous permafrost which occurs generally in valley bottoms, particularly where there is fine-grained sediment and a thick vegetation mat. North facing slopes are also underlain by permafrost, but south facing slopes are generally free of it (Péwé, 1975).

REGIONAL VEGETATION

The Flora

About 640 species and subspecies of vascular plants are likely to occur within the area shown by Figure 3. This estimate is based upon the species range maps published by Hulten (1968). W.S. Benninghoff (Holmes and Benninghoff, 1957) collected approximately 400 species of vascular plants and 61 bryophyte species from the U.S. Army test area, Fort Greely, near Delta Junction (Fig. 2). Our limited vegetational investigations near lowland coring sites yielded about 160 species of vascular plants. Roughly one quarter of the regional flora is restricted to tundra environments and thus is not now present in the Tanana Lowland. Appendix A lists vascular plants found at each of four localities visited in 1973.

The Vegetation

Nearly all the region shown in Figures 2 and 3 is covered by tundra or taiga. The term "taiga" is defined by LaRoi (1967, p. 229) as "wooded vegetation of boreal-subarctic latitudes and subalpine elevations that occupies the climatic zone adjacent to the treeless tundra." The remaining areas are barren rock or snow and ice on mountain peaks and sparsely-vegetated outwash plains of the major rivers. Tundra and taiga are broadly defined vegetation categories which can be further subdivided into vegetational subtypes which reflect a variety of local influences upon the vegetation. Among those major influences are fire history, altitude, slope aspect, and the texture, moisture content and temperature of the soil.

Tundra

Two general types of tundra are found in the region: alpine tundra and moist tundra (Viereck and Little, 1972). Alpine tundra is generally sparse vegetation of low heaths, prostrate willows, Dryas, grasses, sedges, and other low herbs. It is found on high rocky ridgetops of the Yukon-Tanana Upland and in the Alaska Range, usually above 900 meters.

Moist tundra is most widespread along the northern foothills of the Alaska Range, generally above 800 meters. In areas where there are persistent strong local winds, such as near Donnelly Dome in the Delta River Valley, patches of shrubby moist tundra occur with scattered stunted spruce at somewhat lower altitudes (Fig. 4). The moist tundra of the Alaska Range northern foothills is generally much shrubbier than the cottongrass tussock-dominated moist tundra common to much of the Seward

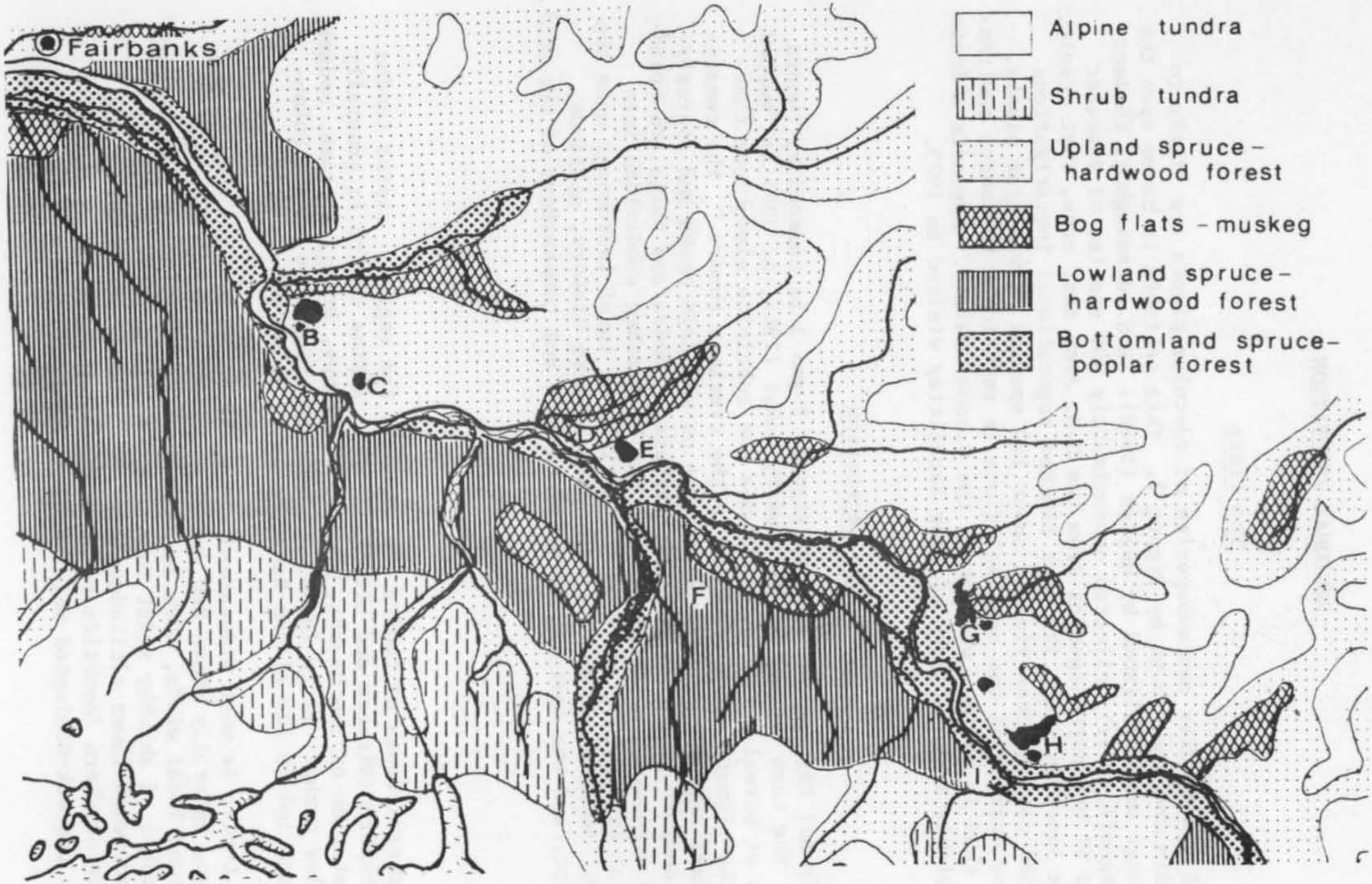

Fig. 3. Vegetation map of Middle Tanana Valley.

Fig. 4. Donnelly Dome near Delta River has several types of vegetation growing in its vicinity. Stunted spruce occur in shrubby moist tundra vegetation which includes abundant dwarf birch, willows, heaths, and herbs. Elements of alpine tundra also can be found in the area. Photograph taken in July, 1973.

Peninsula and the northern foothills of the Brooks Range. The shrubby moist tundra of the interior foothills commonly includes dwarf birch, resin birch, heaths, willows, occasional patches of alders along streams, and tussocks of cottongrass (Eriophorum). Other sedges, grasses, Dryas, and various other herbs also contribute to the vegetation of the shrubby moist tundra.

Taiga

The vegetation of the interior Alaskan taiga has been described by Lutz (1956), Viereck and Little (1972), Viereck (1973), Drury (1956), LaRoi (1967), and others. Only a few species of trees occur in the region: white spruce (Picea glauca (Moench) Voss), black spruce (Picea mariana (Mill.) B.S.P.), paper birch (Betula papyrifera Marsh.), quaking aspen (Populus tremuloides Michx.), balsam poplar (Populus balsamifera L.), and larch (Larix laricina (DuRoi) K. Koch). Yet the taiga displays a surprisingly complex mosaic of vegetational sub-types which reflects fire history and other previously-mentioned environmental influences.

Fire history plays a major role in influencing vegetational patterns in interior Alaska. Nearly all of the vegetated interior has been burned at least once during the past 250 years, and many areas have been burned repeatedly during that period (Viereck, 1973). An estimated average of 0.6 to 1.0 million hectares (1.5-2.5 million acres) burned annually during the period of 1900-1940 (Barney, 1971). Fires are most severe and widespread during warm, dry weather conditions which commonly occur in May, June, and July. Fires in the Upland often spread over large areas due to a lack of natural fire barriers, such as large rivers. The south-facing slopes are particularly susceptible to fires (Viereck, 1973). The successional pattern is variable, due to influences such as severity and frequency of fires, characteristics of substrate, microclimate, and proximity to seed sources.

Four generalized vegetation types are found within the taiga: (1) closed spruce-hardwood forest of the uplands; (2) open spruce-hardwood forests of the lowlands; (3) white spruce-balsam poplar closed forests of bottomlands; (4) muskeg and treeless bogs.

Closed spruce-hardwood forests cover most of the Yukon-Tanana Upland and parts of the northern foothills of the Alaska Range (Fig. 3). These forests consist of pure and mixed stands of spruce, aspen, birch, willow and alder. This patchwork pattern reflects both influences of microenvironment and fire history. If left undisturbed by fire, white spruce gradually replaces birch, aspen, willow, and alder. Slope aspect influences upland vegetational patterns (Krause et al., 1959). For example, black spruce is most common on cool moist north-facing slopes, whereas white spruce, aspen, and birch are most common on warmer, well-drained south-facing slopes. The understory of the upland spruce-hardwood forests includes a variety of shrubs, such as willows, wild rose (Rosa acicularis), alder, and heaths. Groundcover is commonly a thick layer of mosses in stands of spruce.

Open spruce-hardwood forests are widespread in the lowlands. They also occur on north-facing slopes of the uplands, but the scale of the map (Fig. 3) does not permit differentiation from upland closed forests. Black spruce and, occasionally, larch are the most common trees. Permafrost is usually close to the surface in the areas covered by this vegetation. The understory of this vegetation includes willows, rose, heaths, and in some places, dwarf and resin birch, mosses, grasses, and sedges.

Closed white spruce-balsam poplar forests occur on the floodplains of the Tanana River and some of its tributaries (Fig. 5). These forests include alders, willows, prickly rose (Rosa acicularis), and other shrubs. Ground cover often includes Equisetum and mosses. General patterns of vegetational succession on Tanana Valley floodplains are described by Viereck (1970).

Bog flats underlain by permafrost are a common occurrence in valley bottoms of the Yukon-Tanana Upland and scattered parts of the Tanana Lowland. Bog flats interlaced with forested levees and pitted with thermokarst lakes can be seen in the lower Healy River Valley (Fig. 6). Vegetation and geomorphic processes in similar bog flats in the Upper Kuskokwin Valley to the west were studied by Drury (1956). Common components of bog vegetation are grasses, sedges, mosses, various aquatic plants, and scattered shrubs such as heaths, willows, dwarf birch, and resin birch.

Bogs with tussock sedges, heaths, sphagnum moss, and sparsely distributed black spruce and larch are called "muskeg" (Viereck, 1973). Figure 7 shows an area of muskeg near Fairbanks.

Surface Pollen Spectra from the Tanana Valley

Interpretation of past vegetation from assemblages of fossil pollen is often facilitated by comparison with modern pollen spectra produced by known vegetation types (Wright, 1967). To supplement published data on modern pollen rain in Alaska and Canada (e.g. Lichti-Federovich and Ritchie, 1968; Birks, 1973; Bartley, 1967; Matthews, 1970; Terasmae, 1967a), surface samples from lakes and ponds (Fig. 3) in the Tanana Valley were analyzed for pollen content. Pollen spectra from the sampling localities are compared in Figure 8. All samples came from sites surrounded by closed spruce-hardwood forest, open spruce-hardwood forest, or

Fig. 5. Vegetation west of Healy Lake includes stands of white spruce and balsam poplar on terraces of the Tanana River and mosaic forest (closed spruce-hardwood forest) growing on the ridges of the Yukon-Tanana Upland. Active floodplain of the Tanana River is quite barren of vegetation because of frequent shifts of channels and formation of overflow icings (aufeis) in winter. Photo was taken in late September, 1970.

Fig. 6. Bog flats east of Healy Lake are pitted with thermokarst ponds and interlaced with forested levees. The bedrock hills beyond the bog flats are covered by closed spruce-hardwood forest. Ridgetops in the distance are covered with alpine tundra vegetation. Photo was taken in late September, 1970, after a snowfall had mantled the highest portions of the Yukon-Tanana Upland.

Fig. 7. Muskeg vegetation near Fairbanks, Alaska is underlain by permafrost. Vegetation includes cottongrass tussocks, dwarf birch, resin birch, willows, scattered black spruce, and a variety of herbs and mosses. Larch is also found in muskeg areas of the Middle Tanana Valley.

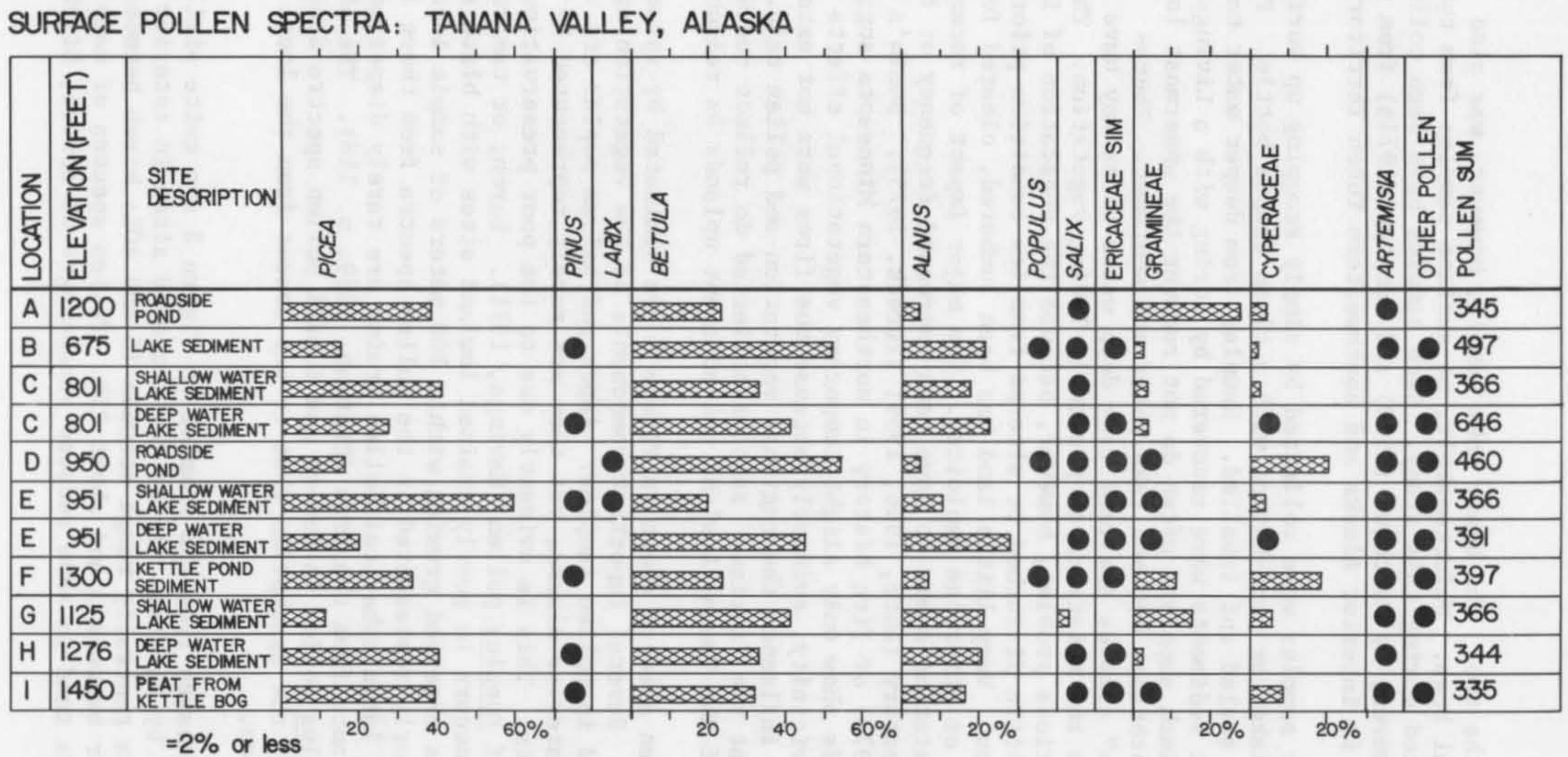

Fig. 8. Surface Pollen Spectra Diagram from the Middle Tanana Valley.

a combination of the two. The Healy Lake sample, however, was also influenced by local bogs. Unfortunately, no surface samples from tundra areas were collected during this study. Such samples have been collected and described, however, by Matthews (1970) and Rampton (1971a) from upland tundra sites in interior Alaska and southwestern Yukon Territory.

Shallow-water samples were collected by simply scooping up surface samples from the lake- or pond-bottom with a clean sample bottle. Filled bottles were then sealed and labelled. Samples from deeper water taken from the uppermost sediments were recovered by coring with a Livingstone Piston Sampler. Such samplers often do not recover the uppermost loose sediment at the interface between lake water and sediment. Therefore, the "surface" samples analyzed from deep water sites may have been deposited prior to the existence of presently-living vegetation. This is probably not a serious problem, however, because the vegetation of interior Alaska has been little disturbed or altered from its condition prior to the days of exploration. Very little land has been lumbered, cleared for agricultural use, or otherwise exploited. The major impact of recent human activity upon vegetation seems to have been increased frequency of fires during the past century (Lutz, 1956, 1959; Viereck, 1973). Swain's recent detailed study (1973) of fire history in northeastern Minnesota suggests that pollen records show only slight temporary vegetational effects following fires in the vicinity, evidently because the fires were not extensive enough to greatly influence the regional vegetation and pollen rain. Thus the assumption that the "surface" samples collected do reflect contemporary vegetation of the Tanana Lowland and adjacent uplands is reasonable.

All the pollen spectra shown in Figure 8 are dominated by spruce, birch, and alder. Several important components of the vegetation are poorly represented in pollen samples. Aspen and balsam poplar are very common trees in interior Alaska, yet they are rarely represented by their pollen in sediments. This is evidently due to the poor preservational characteristics of _Populus_ pollen (Havinga, 1971). Larch, or tamarack (_Larix laricina_) occurs in poorly drained lowland sites with black spruce. Although larch was observed growing within 100 meters of sample localities B and D, it is poorly represented in the pollen spectra from those localities because the large spherical pollen grains are rarely dispersed more than a short distance from the tree (Erdtman, 1969, p. 118). The absence of larch and _Populus_ pollen in modern and fossil pollen spectra does not, therefore, justify the assumption that it was absent from the local or regional vegetation.

Pollen percentages from the samples in Figure 8 are quite similar to those obtained by Matthews (1970) for forested sites in interior Alaska. Spruce percentages generally range between 15 and 40%; birch between 20 and 50%; and alder between 3 and about 25%. Pollen spectra of samples from shallow ponds tend to show reduced percentages of spruce, birch, and alder because of the significant local influence of pollen of grass and sedge that rim such ponds. One shallow water sediment sample from Quartz Lake (Fig. 8, Locality E) shows an anomalously high percentage of spruce pollen. I believe this can be explained by the fact that the sample was collected close to shore, where floating spruce pollen is likely to be concentrated in disproportionately large quantities by wind and waves. The morphology of spruce pollen tends to favor its remaining in suspension or floating at the surface longer than most other pollen types common to the region. This behavior is inferred from observations of pine pollen in lake water by Davis and Brubaker (1973, p. 643). Pine pollen is smaller than spruce pollen, but its morphology is comparable.

Pine pollen occurs in trace amounts in 6 of the 11 surface samples, but pine does not now grow in interior Alaska. The nearest likely source of the pine pollen is more than 300 km to the east of Lake George, in the Yukon Territory, where Pinus contorta now grows (Hultén, 1968). Its presence in small amounts in contemporary sediments is due probably to long-distance transport in the atmosphere.

Although the number of surface samples is small, and all come from sites within the spruce-birch-aspen forested portion of the region, several generalizations can be made. First, the samples reconfirm the validity of Faegri and Iversen's observations (1964) that small ponds are likely to yield pollen records that reflect local vegetation more than regional vegetation. Second, surface samples from different depths within the same lake show significant variations in pollen percentages (Localities C and E, Figs. 3 and 8). This suggests that (1) the samples were not deposited at the same time, or (2) pollen underwent differential sedimentation (Davis and Brubaker, 1973), or (3) pollen was redeposited by dynamic lake processes (M.B. Davis, 1968, 1973). Thus it is likely that cores taken from different depths within the lake will display some differences in contemporaneous pollen percentages of ancient as well as modern sediments. Third, it is clear that several tree species which are important elements of the forest vegetation are very poorly represented in the modern pollen rain, as are most shrubs and herbs. Reconstructions of former vegetation are severely limited by the fact that important elements of the vegetation are poorly represented in the pollen record. At best, only a crude approximation of general vegetation type can be inferred from the modern and ancient pollen spectra from interior Alaska.

the sides because of the significant local influence of pollen of grass and sedge that rim each pond. One shallow-water sediment sample from Quartz Lake (Fig. 4, locality 8) shows an anomalously high percentage of spruce pollen. I believe this can be explained by the fact that the sample was collected close to shore, where floating spruce pollen is likely to be concentrated in disproportionately large quantities by wind and waves. The morphology of spruce pollen tends to favor its remaining in suspension or floating at the surface longer than most other pollen types common to the region. This behavior is inferred from observations of pine pollen in lake water by Davis and Brubaker (1973, p. 463). Pine pollen is smaller than spruce pollen, but its morphology is comparable.

Pinus pollen occurs in trace amounts in 4 of the 11 surface samples, but pine does not now grow in interior Alaska. The nearest likely source of the pine pollen is more than 500 km to the east of Lake George, in the Yukon Territory, where *Pinus contorta* now grows (Hulten, 1968). Its presence in small amounts in contemporary sediments is due probably to long-distance transport in the atmosphere.

Although the number of surface samples is small, and all come from sites within the spruce-birch-aspen forested portion of the region, several generalizations can be made. First, the samples reconfirm the validity of Tsukada and Tsukada's observations (1964) that small ponds are likely to yield pollen records that reflect local vegetation more than regional vegetation. Second, surface samples from different depths within the same lake show significant variations in pollen percentages (localities 6 and 8, Figs. 3 and 4). This suggests that (1) the samples were not deposited at the same time, or (2) pollen underwent differential sedimentation (Davis and Brubaker, 1973), or (3) pollen was redeposited by dynamic lake processes (M.B. Davis, 1968, 1973). Thus it is likely that cores taken from different depths within the lake will display some differences in contemporaneous pollen percentages of ancient as well as modern sediments. Third, it is clear that several tree species which are important elements of the forest vegetation are very poorly represented in the modern pollen rain, as are most shrubs and herbs. Reconstructions of former vegetation are severely limited by the fact that important elements of the vegetation are poorly represented in the pollen record. In fact, only a crude approximation of general vegetation type can be inferred from the modern and ancient pollen spectra from interior Alaska.

PREVIOUS INVESTIGATIONS

The status of Quaternary research in interior Alaska as of the mid-1960's was summarized by Péwé (1965) and Péwé et al. (1965). Much research effort has centered on the study of Quaternary deposits of the Fairbanks area and the fossils they contain (Péwé, 1965, 1966; Sellman, 1967; Guthrie, 1968a, 1968b; Matthews, 1968, 1970, 1974a). The stratigraphy of the organic-rich silts that form perennially-frozen valley fills in the Yukon-Tanana Upland has been subdivided into several units that include deposits of Illinoian, Wisconsin and Holocene age (Péwé, 1965, 1975). The characteristics of the loess deposits of interior Alaska have been described by Péwé (1965, 1968).

Glacial deposits in the Alaska Range within the study area were described by Moffit (1942), Holmes and Benninghoff (1957), Holmes (1965), Holmes and Foster (1968), and summarized by Péwé (1965); and more recently reconnaissance studies by T.D. Hamilton (1973) havd added refinements to our knowledge of regional glacial stratigraphy. Péwé differentiates glacial deposits of two major late Pleistocene glaciations. The Delta Glaciation was the earlier and most extensive event in terms of area covered by ice. Deposits of the younger event are from the Donnelly Glaciation. Péwé correlates the Delta Glaciation with Illinoian and Donnelly with the Wisconsin Glaciation of the mid-west (1965). Hamilton's field studies (1973) and aerial photointerpretations suggest that the Donnelly deposits represent several glacial advances, recessions, and stillstands. All studies of the glacial deposits have been hampered by a paucity of radiocarbon dates or other reliable means of dating events; therefore, glacial chronology of the Alaska Range remains very tentative. In the absence of local means of dating glacial events, inferences can be made from relatively well-documented glacial sequences to the east near the Alaska-Yukon border (e.g. Rampton, 1971b; Denton, 1974). It is reasonable to infer that major events of the two regions are correlative.

Local glacial deposits and features in the highest peaks of the Yukon-Tanana Upland have been mapped by Péwé et al. (1967). Upland glacial deposits have been correlated with the Delta-Donnelly sequence in the Alaska Range. Although Neoglacial deposits have been recognized throughout the Alaska Range, none are known to exist in the Yukon-Tanana Upland.

A number of Tanana Valley lakes have been investigated by geologists and biologists. Blackwell conducted the geomorphic study of the Harding Lake, Birch Lake, and Quartz Lake areas (Blackwell, 1965). The Quaternary history of the Healy Lake area was investigated by Ager (1972). An ecosystem study of Lake George was conducted by Swartz (1966). Lake George was also briefly discussed in a reconnaissance study of the geology of the Johnson River area by Holmes and Foster (1968).

Thermokarst lakes and ponds in the upper Tanana Valley were studied by Wallace (1948) and in the Upper Kuskokwim Valley west of the Tanana Valley by Drury (1956). Thermokarst processes in the Healy Lake area are discussed by Ager (1972).

Most previous Quaternary paleoecological information from interior Alaska has been derived from studies of micro- and macro remains of plants and animals preserved in the thick sequences of perennially-frozen silty colluvium in the Yukon-Tanana Upland. Thousands of fossil mammal bones and occasional carcasses have been recovered during placer mining activity. Péwé (1966a) provides a list of mammal species that have been identified. Large-mammal fossil assemblages have been studied in detail by R.D. Guthrie. His investigations resulted in an attempt to reconstruct the late Pleistocene large-mammal community and to infer aspects of environmental conditions from the probable habitat requirements of such a community. Since the assemblage was dominated by mammoth, bison, horse, and other grazing animals, Guthrie (1968a) suggests that the late Pleistocene upland vegetation was grassland-tundra.

Small mammal fossils recovered from these deposits have been analyzed by Repenning et al. (1964) and Guthrie (1968b). The assemblages include a number of species which no longer occur in the uplands today. The modern distribution and habitat requirements of living representatives of those species led the investigators to infer a widespread tundra or tundra-like environment in the Yukon-Tanana Upland in late Pleistocene time.

Matthews obtained fossil insect assemblages from Upland colluvium deposits. His analysis demonstrates that many of the fragmentary fossils could be identified and used to interpret past environmental conditions (Matthews, 1968). His analysis suggests that presently forested portions of the uplands were formerly "tundra" in late Pleistocene time.

Although considerable effort has been directed at paleoecological investigations of mammal and insect remains in interior Alaska, little paleobotanical research has been attempted until recently. Early work by Chaney and Mason (1936) was limited to the identification of a small collection of plant macrofossils from the frozen upland silt deposits. Hansen (1953) examined the pollen content of shallow peat deposits along the Alaska Highway and other interior roadways, but his research is of little value to those who seek a relatively detailed paleoenvironmental reconstruction, because his interest was in determining forest history only. His pollen profiles span only a few thousand years and neglect non-arboreal components of the vegetation. Péwé (In press; pers. com. 1974) collected peat and organic silt samples from the "muck" exposures in the Yukon-Tanana Upland. Some of the samples were analyzed for pollen content by E.S. Barghoorn. Although the data were limited, they provided some of the first evidence of major vegetational changes in the interior during the Quaternary, such as dramatic lowering of the tree line and expansion of tundra-like vegetation during late Pleistocene glaciations.

The most significant previous palebotanical data from the interior were provided recently by Matthews (1970, 1974a). His research is based upon pollen analysis and identification of plant macrofossils from samples of Upland colluvium. A 27-meter core through a perennially-frozen valley fill in Isabella Basin, near Fairbanks, was investigated by Brown et al. (1969). Although the primary purpose for obtaining the core was to study permafrost and sediment stratigraphy, subsamples from irregular intervals were submitted to Matthews for pollen and macrofossil analysis. His study (1974a) provides the longest record of late Quaternary vegetational history to date for interior Alaska, spanning about 35,000 years. In addition to providing a regional framework from which to proceed with more detailed pollen investigations, the study is enhanced by results of macrofossil analysis that provide important information about plants not represented in the pollen record.

There are, however, compelling reasons to seek supplementary pollen evidence from deposits other than colluvium. Pollen records from colluvium are likely to be incomplete due to presence of unconformities. Preservation of pollen is often poor, which can result in misleading pollen spectra dominated by pollen types more resistant to deterioration. Reworking of sediments by solifluction, gullying, and thermokarst processes can mix pollen from old and young horizons, again yielding potentially misleading results (Terasmae, 1967b, 1968; Matthews, 1970).

Some shallow cores from "Hidden Lake," near Healy Lake, and a peat core from a bog have been analyzed by J.H. Anderson (1974). The cores span only a few thousand years time. Studies in the Healy Lake area by Ager (1972) suggest that the Hidden Lake sediments are a potentially unreliable source of pollen record because the lake is very shallow and is almost certainly of thermokarst origin. Anderson's peat core came from the upper 1.5 meters of Johnson River Bog. A 3-meter core from the same bog is described in this report.

Pollen histories from elsewhere in Alaska and northwestern Canada permit useful comparisons between regions for part or all of the time span represented by the cores analyzed in this report. Pioneering pollen investigations in northern Alaska by Livingstone (1955) were followed by research in western Alaska by Colinvaux (1964, 1967a, 1967b), Colbaugh (1968), and Matthews (1974b). Schweger (1973) conducted extensive pollen analyses of deposits associated with the Onion Portage Early Man site (Anderson, 1968) in northwestern Alaska. Schweger is also conducting an investigation of pollen history in the Tangle Lakes area, south of the Tanana Valley (pers. com., 1973). In southern Alaska, research by Heusser (1960) and Sirkin and Tuthill (1969) provides vegetational history for the past 14,000 years.

Several investigators have contributed to the reconstruction of late Pleistocene vegetational history of northwestern Canada. A pollen record spanning the past 31,000 years was obtained from Antifreeze Pond near the Alaska-Yukon border by Rampton (1971a). The Antifreeze Pond pollen history is of particular interest to the present investigation because of its relative proximity to the Tanana Valley and the fact that it spans all of late Wisconsin and Holocene time.

Borns and Goldthwait (1966) include in their report a pollen diagram of Holocene age from a peat bog near Kaskwulsh Glacier, Yukon Territory. J.H. Anderson (1970) studied postglacial vegetational history of the Atlin region, near the British Columbia-Yukon border.

Lichti-Federovich (1973, 1974) analyzed pollen from frozen Late Pleistocene sediments in the Crow Basin and from the Porcupine River in northern Yukon Territory. Terasmae and Hughes (1966) report the results of research on the pollen from the Ogilvie Mountains in northern Yukon Territory. In other publications, Terasmae discusses aspects of paleoecological problems in northwestern Canada (1967b, 1968). Studies in the Mackenzie District, Northwest Territories, are discussed by MacKay and Terasmae (1963), Ritchie and Hare (1971), and Ritchie (1972).

METHODOLOGY

Field Methods

Core Site Selection

During the 1972 and 1973 summer field seasons, surface samples and cores of pollen-bearing sediments were collected from localities in the Tanana Valley (Fig. 2). The analysis of those samples forms the basis for this investigation.

Selection of coring localities was based on several considerations. Accessability was a major factor, and it is partly because of the relative ease of access to several major lakes by road or motor boat that the Tanana Valley was selected as the study area. Not all lakes are suitable for obtaining a reliable pollen record, however. Hundreds of lakes and ponds dot the lowlands of the interior, but most should be eliminated as coring sites because of their probable youthful age and modes of origin by thermokarst processes. Many lowland lakes are also shallow, and whether or not the lakes formed by thawing of permafrost, shallow water creates conditions conducive to mixing of lake-bottom sediments. Shallow lake sediments are likely to be disturbed by wave activity, grounding ice pans, and perhaps by formation of "bottom ice", as described by Nichols (1967a; 1967b). Most ponds on Donnelly-age glacial drift near the Alaska Range were avoided because of the likelihood they would yield only Holocene age records. Some ponds on older Delta drift are probably not original kettle ponds but formed by thermokarst processes.

The focus of the study was upon the major lakes along the north side of the Tanana Valley. Blackwell's investigations (1965) of Birch Lake, Quartz Lake, and Harding Lake suggest that they were formed during the Delta Glaciation (Illinoian?) by rapid outwash damming of minor south-flowing tributaries by the Tanana River. Lake George was evidently formed by similar processes in Late Pleistocene time (Swartz, 1966). Harding Lake was eliminated from consideration due to its much greater depth and the possibility that its sediments have been disturbed by fault movement within the lake, as suggested by Blackwell (1965). Healy Lake was cored in an effort to date more precisely the time of lake formation, although Ager's previous investigations (1972) suggest that the lake is an unlikely source of a reliable regional pollen record due to its shallow depth, probable youth, highly fluctuating lake levels, and partial thermokarst origin.

Coring Methods

The Johnson River Bog (Fig. 2) was cored with a Hiller Peat Sampler. The lake sediment cores, however, were obtained with a modified

Livingstone Piston Sampler, the use of which is discussed by Deevey (1965). Both devices are described by Wright et al. (1965). Piston-coring was conducted from a portable floating platform secured with six heavy anchors. The platform was constructed from two 4-man Avon inflatable rafts and a plywood and lumber deck (Fig. 9). The floating platform was equipped with a 3-HP outboard motor.

Once the raft was anchored at a suitable locality, sectioned aluminum casing was lowered to the lake bottom and allowed to penetrate the sediments slightly. The piston sampler was then lowered through the casing to begin coring. Cores were taken in 1-meter increments, using aluminum tubes with a steel cutting bit as the core barrel of the sampler. Each tube of sediment was immediately sealed with corks and labelled. To prevent further possible dessication, corked ends of the tubes were sealed with melted paraffin, usually the same day they were collected.

Weather conditions are critical to the success of this type of coring operation from a floating platform. Even moderate waves interfere with coring by slightly shifting the raft's position. Such a shift could tilt or bend the casing, especially when coring in water deeper than 8 meters, and occasionally caused the piston sampler to bind or catch on the bottom of the casing when extracting the sampler. When that occurred, the withdrawal of both sampler and casing was sometimes necessary, and sampling operations ceased at that site. Sudden wind and weather changes are common in interior Alaska, and consequently, the selection or coring localities had to be tempered by anticipation of weather conditions. It is generally accepted practice, when coring lake sediments, to raise the cores from the deepest parts of the lake, on the assumption that the oldest, most complete record is likely to be found there. Site selection at Lake George, however, had to be modified because of strong winds blowing periodically from the southwest. The core site was selected to combine deep, but not deepest, water with some slight protection from sudden severe wind and waves.

Core-filled tubes were stored in a crate until the end of the field season, when they were transported by automobile to The Ohio State University. There they were stored in a $4^{\circ}C$ cold room.

Laboratory Methods

Sediment cores underwent several stages of analysis in the laboratory. This section outlines the methods used to study core samples through the use of x-radiography, sediment analysis, pollen analysis, and radiocarbon dating. Results of these studies will be discussed in the chapters that follow.

Fig. 9. Piston-coring from a floating platform. Photograph taken July, 1973.

X-radiography

Prior to extruding the sediment cores from their aluminum tubes, cores were X-rayed with an industrial X-ray unit equipped with a 150 mV head placed at a distance of 125 cm from the cores. After a series of experimental exposures, the most satisfactory settings for producing the most detailed images on the X-radiograph were 10 mA and 100 kV for 35 seconds. Additional experiments may have further improved the exposures, but the investment in time and film did not justify additional trials. The resulting X-radiographs provide a permanent record of the structures of the sediment cores prior to disturbance by extrusion from the tube. Some structures visible on the X-ray films were not discernable to the naked eye when the cores were extruded and examined. X-rays also clearly reveal the topmost portions of some core sections that had been contaminated by mixing during the coring operation. Ordinarily, the mixing occurs only if the piston slips out of position prior to the sampler's reaching proper sampling depth and can therefore result in mixed younger sediment entering the tube before sampling is supposed to begin. Such contamination can sometimes be easily detected due to differences in sediment type, contorted layers, or a watery, bubbly appearance. Occasionally, however, it is more difficult to detect visually, and the X-radiographs readily reveal the boundary between loose contaminated sediments and denser noncontaminated sediments.

Subsampling procedures

Core sections to be analyzed were removed individually from storage in the cold room and extruded into a pre-labelled aluminum trough lined with several thicknesses of Saran plastic wrap. The cores were then measured, sliced open lengthwise, and sediment textures and structures, macrofossil content, and color were described. A Munsell Soil Color Chart was used to describe the colors of the moist sediments.

After description was completed, the section was subsampled for pollen analysis. With a clean laboratory spatula, samples of roughly 1 cm^3 were removed from the inner portion of the core, after the surface to be penetrated had been freshly scraped clean of possible contamination. Samples for pollen analysis were removed from 10 cm intervals throughout the core, starting with the uppermost centimeter from the upper section. Each moist sample was pressed into a stainless steel subsampler machined to accommodate a 1-cm^3 volume sample. The excess was scraped off flush with the flat surface of the sampler to insure uniform sample size. The same subsampler was used for all samples to further insure uniform volumes. The subsampler was carefully washed between samples to prevent contamination. Replicate samples of sediments were taken from the same intervals, placed in stoppered glass vials, labelled, and stored in the cold room.

Additional subsamples were removed from the cores for sediment analysis and radiocarbon dating. Samples for sediment analysis were removed from the core at irregular intervals. A sample weight of 100 grams (moist) was obtained whenever possible for sediment analysis, but due to the small core diameter and the competing uses for the cores, sediment samples were often smaller.

Pollen data were used whenever possible to guide the selection of core sections used for radiocarbon dating. Significant vegetational changes inferred from pollen samples permitted pinpointing of core intervals which would date such events. Extreme care was taken to insure against sample contamination. Subsamples were removed with clean spatulas, scraped to remove outermost sediments, placed on sheets of aluminum foil, and dried in a laboratory oven. Dried, labelled samples were wrapped in several layers of aluminum foil and mailed to radiocarbon-dating laboratories. Most of the samples were sent to Teledyne Isotopes, Westwood, New Jersey. Two samples were dated by the University of Alaska Radiocarbon Dating Laboratory, and two additional samples were dated by Dicar Radioisotopes, Cleveland, Ohio.

Pollen analysis procedures

Pollen and spores were concentrated from 1-cm^3 subsamples of core sediments following procedures modified from Faegri and Iversen (1964) (Appendix B). The procedures involve treatment with 7% NaOH, followed by acetolysis, then a bromoform separation. A few samples required additional treatment with hot hydrofluoric acid to remove abundant clays. An additional step was used for the two longest cores analyzed. To each sample from Birch Lake Core II and the core from Lake George, 1 or 5 tablets containing darkly-stained Lycopodium clavatum spores were added. These tablets have come into routine use only recently and are discussed by Stockmarr (1971), who initiated their manufacture. Each tablet contains a known quantity of Lycopodium clavatum spores. By adding a "spike" of a known number of exotic spores or pollen to a sample of known volume, one can calculate concentration of naturally occurring pollen and spores per unit volume of sediment by determining the ratio of introduced exotics to non-introduced pollen and spores. This technique is a modified version of that described initially by Benninghoff (1962). Determination of pollen concentration in sediments can be especially useful if coupled with sedimentation rates determined from counting varves or radiocarbon dates. The resulting data can be expressed as pollen and spores accumulating per cm^2 per year, referred to as Absolute Pollen Influx (API) (Maher, 1972). The application of API data to this research will be discussed in the following chapter.

Because Lycopodium clavatum is a vascular plant that grows within the study area (Hultén, 1968), it is not an ideal spore type to introduce into pollen samples from interior Alaska as an exotic "spike." Its naturally-occurring spores were only rarely encountered, however, in samples examined from the other cores which had not been subjected to the "spiking" procedure. Lycopodium clavatum tablets were the only exotic "spiking" tablets available when the processing was done. To insure that I would not confuse introduced Lycopodium clavatum spores with the occasional naturally-occurring ones in my samples, I modified the processing procedure somewhat by reducing the acetolysis treatment time from 30 minutes to 5 minutes. Acetolysis stains pollen and spores darker as treatment time increases. Thus, the reduction in treatment time results in naturally-occurring spores and pollen which are much lighter in color than the introduced grains, darkly stained by acetolysis treatment prior to tablet manufacture.

Residues of pollen and spores resulting from core sample processing are mounted in glycerine containing a small amount of Safranin stain, on pre-labelled microscope slides. The glycerine is mixed with a clean dissecting needle to insure even distribution of pollen before carefully placing a coverslip over the drop of liquid. The slides were placed in protective storage trays until counted.

Pollen reference material

About 180 taxa of vascular plants were acquired for the purpose of producing a modern pollen reference collection of northern plants. The collection supplements published pollen ans spore identification keys and photographs. Mr. Steven Buttrick collected and identified plant specimens during the 1973 field season, and those bearing pollen or spores were processed to provide reference slides (Appendix C). Additional plant specimens for pollen reference material were obtained from the polar plant collection of The Ohio State University Herbarium. To further enlarge the pollen reference collection, several hundred reference slides were traded with other palynology laboratories in the United States and Canada. In addition, I had access to the extensive pollen reference collection of Dr. Paul Colinvaux. The many reference slides thus available permitted more reliable identification of some pollen grains and spores than might otherwise have been possible.

Preliminary identification of pollen relied on publications such as McAndrews et al. (1973), Faegri and Iversen (1964), Erdtman (1965, 1969, 1972a, 1972b), and Erdtman and Sorsa (1971). Final determinations, when there was doubt, depended upon comparison with pollen reference material.

Counting procedures

Pollen samples were examined with a Leitz Ortholux microscope at magnifications of 250X, 400X (for routine counts), and 900X (oil immersion). Oil immersion was used when difficulties in identification were encountered. The microscope slides were examined in non-overlapping parallel traverses. Each grain encountered was identified, if possible, and tabulated on an array of counters labelled with the common pollen and spore types for the area. Less common types were recorded on preprinted forms which listed most types likely to be encountered. Whenever possible, at least 300 pollen grains were counted per slide. Those pollen grains and spores that remained unidentified but had definite morphological characteristics were tabulated as "undetermined" types. The notation "sim." appears as a suffix to a number of pollen and spore taxa in the pollen diagrams; it means that the pollen grains or spores belong either to the taxon indicated or to a taxon of comparable rank which has morphologically indistinguishable pollen or spores. The suffix "comp." is used in one case to indicate a favorable comparison with the taxon to which it is assigned, but identification is uncertain. The three terms described above follow the notations suggested by Benninghoff and Kapp (1962). The term "indeterminate" is used to designate grains that are too crumpled or deteriorated to permit identification.

In most cases, the microscope slides were scanned briefly after the counts had been completed to search for minor elements. Pollen and spore types encountered during such scans were recorded on the tabulation sheets with a distinguishing symbol to prevent their being counted as part of the pollen sum. Their presence, even in trace amounts, was considered to be of sufficient importance to justify including them on the pollen diagram, but to again distinguish them from the grains included in the pollen sum by means of a special symbol (o).

Statistical procedures

Pollen percentages were calculated on the basis of a pollen sum which excluded aquatic and semi-aquatic pollen types, spores and algae. The pollen sum was usually 300 grains. Those samples that yielded pollen sums of significantly less than 300 grains had very low pollen concentrations and often contained a higher proportion of indeterminate palynomorphs. Although the aquatic and semi-aquatic pollen types, the spores, and algae were not included in the pollen sum, their contribution to the sample was calculated as a percent of the pollen sum. That procedure was also used to calculate percentages of indeterminate types.

The calculation of Absolute Pollen Influx followed the procedures described in Maher (1972). Briefly, the calculations were made in the following manner. It is assumed that the previously-described sampling procedures yielded sediment samples of equal volume. A known number of "exotic" spores was introduced into the samples, as previously mentioned in the discussion of laboratory processing procedures. When microscopic determinations were being made, every exotic spore encountered during the count was tabulated, along with the other grains. When counting was completed, the total number of pollen grains was tabulated, as well as totals for the non-exotic spores, the two algae types, and the exotic spores. Then the total concentration of pollen grains per cm^3 of moist sediments were calculated, using the following relationship where

N = Number of Lycopodium marker grains added to sample

R = Ratio of the number of pollen grains counted to number of grains of Lycopodium tabulated during counting

V = Volume of sediment sample in cm^3

thus: $$\frac{N\ R}{V} = \text{pollen concentration/cm}^3$$

By including the sedimentation rate determined from radiocarbon dated core segments, the pollen concentration can be translated into pollen grains accumulating per cm^2 per year. Thus, where

S = Sedimentation rate of lake sediments at core site expressed in cm/year,

the equation becomes

$$\frac{N\ S\ R}{V} = \text{pollen grains/cm}^2\text{/year.}$$

(Maher, 1972)

By substituting the number of grains counted of a particular taxon for the total of pollen grains counted, the yearly accumulation per cm^2 for that taxon can be determined. Such calculations were made for the major pollen types encountered in the Birch Lake Core II. The resulting data are presented in the next chapter. Taxa which occurred in low concentrations were combined under headings such as "Other Pollen" and "Spores." This was done to avoid misleading calculated pollen concentrations based upon perhaps a single grain encountered during the counts.

Other variations of the technique have been employed to determine Absolute Pollen Concentration and Absolute Pollen Influx (e.g. Davis, 1965, 1969; Waddington, 1969; Kirkland, 1967). A discussion of these variations and comparability of results can be found in Maher (1972).

Potential sources of error that could significantly alter the calculated accumulation rates of pollen and spores include both field and laboratory techniques and variations in the spore content of the Lycopodium tablets added as a "spike." The potential error from field methods comes from the necessity of extracting core segments from the lake in 1-meter increments. Although great care was taken to insure that succeeding sections extracted from the lake bottom began exactly where the previous section ended, minor errors are likely, due to occasional slight slippage of the piston and occasional loss of the bottom several centimeters of sediment as the corer was raised to the surface. This would introduce error into the calculation of sedimentation rates; if sedimentation was very slow, loss of 5 cm or more of sediment introduces potentially significant error.

Laboratory procedures could potentially introduce error into the determination of Absolute Pollen Influx if sample treatment varied sufficiently to influence the recovery of pollen and spores. Thus, variations in pollen concentrations would be due, in part, to processing rather than to conditions at the time of pollen deposition. This source of error is here considered negligible, however, because the laboratory procedures followed were quite consistent for all samples.

Validity of calculated sedimentation rates is dependent upon the accuracy of radiocarbon dates from core segments. Organic content of core samples used for sediment analysis varied from less than 1% to 17% of dry sample weight. Core segments submitted for radiocarbon assay yielded 1 to 3 grams of carbon, which is considerably less than the 5 grams preferred by dating laboratories. Two samples were undatable because of inadequate carbon yield. Samples from the lowermost 3 meters of Birch Lake Core II and Lake George core contained only small amounts of carbon, which increases the probability of counting error and magnifies the influence of contamination, if any has occurred. Therefore, the calculated sedimentation rates and the Absolute Pollen Influx calculations must be viewed with caution due to these potential errors. The radiocarbon stratigraphy of Birch Lake Core II seems to be of sufficient reliability to construct an Absolute Pollen Influx diagram. The radiocarbon dates from the Lake George core, however, have serious and as yet unresolved discrepancies which prevent the use of that core to calculate API. Further discussion of those cores and the associated radiocarbon dates appears in the following chapters.

A related problem is that of variations in sedimentation rates within an interval bracketed by radiocarbon dates. Ideally, a large number of radiocarbon dates should be used to document changes in sedimentation rates in a core designated for API calculations. When large intervals of core are left undated, serious errors in API calculations could result if a significant change in sedimentation rate occurred within the interval.

API calculations are also dependent for their accuracy upon the reliability of the figure used for the number of introduced exotic spores. According to Dr. Louis J. Maher, Jr., (pers. com. 1974) who supplied me with the Lycopodium tablets, they contain 12,500 ± 500 spores per tablet. That number is based upon determinations made by Jens Stockmarr, who oversees the manufacture of the tablets by a pharmaceutical company (Stockmarr, 1971). By using 5 tablets instead of 1 tablet, individual variations between tablet spore content becomes less significant. Five tablets were used whenever the pollen concentration was known or suspected to be high. For samples with low pollen concentrations, only one tablet was added to avoid counting much greater numbers of Lycopodium spores than indigenous pollen and spores. Each tablet was examined before its use to prevent including chipped or broken ones which would contain fewer spores.

In view of the potential errors from various sources, the results of the API calculations should be viewed with caution, and interpretations must be considered tentative until other data become available from the region.

Sediment analysis procedures

Core subsamples were submitted to the Quaternary Laboratory of the Department of Geology and Mineralogy for sediment analysis. The analyses were done under the supervision of Professor R.P. Goldthwait. Samples had a pretreatment moist weight of about 100 grams. They were dried, weighed, then treated with 30% hydrogen peroxide to remove all organics. The hydrogen peroxide treatment was repeated until reaction ceased. The sample was then redried and weighed to determine weight loss due to removal of organics. Remaining sediments were then subjected to mechanical analysis by dry-sieve and hydrometer techniques as outlined by the American Society of Testing Materials (1964). Data resulting from sediment analysis are included in Appendix D.

BIRCH LAKE

Birch Lake was selected as a primary locality for piston-coring to obtain a long-term pollen record. General criteria for core site selection were previously discussed in the section on fieldwork methods.

Birch Lake is adjacent to milepost 307 of the Richardson Highway and is 77 km southeast of Fairbanks (Figs. 2 and 10). The lake lies within a small east-west trending valley of the Yukon-Tanana Upland. Blackwell's (1965) geological studies at Birch Lake show that the lake is enclosed by bedrock and deposits of organic-rich colluvium on all but part of the western shore. The bedrock ridges along the north and south ends of the lake are composed of Birch Creek Schist and granitic intrusives and are blanketed with loess and colluvium. The west end of the lake is formed by a dam of outwash sand and gravel deposited by the Tanana River during the late Pleistocene.

Two terrace levels in these outwash deposits separate Birch Lake from the modern floodplain of the Tanana River, presently 1.2 km to the west. On the basis of terrace sequence and degree of weathering of the outwash, Blackwell (1965) interpreted the upper terrace to be of Delta (Illinoian?) age and the lower terrace to be of Donnelly (Wisconsin?) age. Blackwell concluded that Birch Lake was probably formed during the Delta Glaciation. This inferred age for the lake made if particularly interesting as a coring locality. The results of this investigation, however, provide no supporting evidence for the formation of Birch Lake during Delta (Illinoian?) time, as will be discussed below. Several small streams enter the lake, some small enough for a person to hop across. There is evidently a small outlet stream at the southwest end of the lake, although it does not appear on the U.S. Geological Survey 15 minute quadrangle map of the area. Additional water is probably lost by groundwater percolation through the coarse outwash dam, as well as by evaporation.

Five lacustrine sediment cores were obtained by piston-coring from a floating platform at Birch Lake. Of those cores, two have been used for pollen analysis and sediment grain-size analysis. Core I was obtained in 1972 in water 5.1 meters deep, west of a bedrock point that extends into the lake from the eastern shore (Fig. 10). A morphometric map of the lake bottom by Blackwell (1965) shows that the bedrock point evidently continues across the lake under water. This east-west trending submerged ridge divides the floor of the lake into two sedimentation basins; the southern basin is the deeper. Core II was taken in 1973 from about the deepest part of that southern basin where the depth was 13.8 m.

Sources of Sediment

One of the major potential sources of inorganic sediment in Birch Lake is loess, both at the present time and during the late Pleistocene

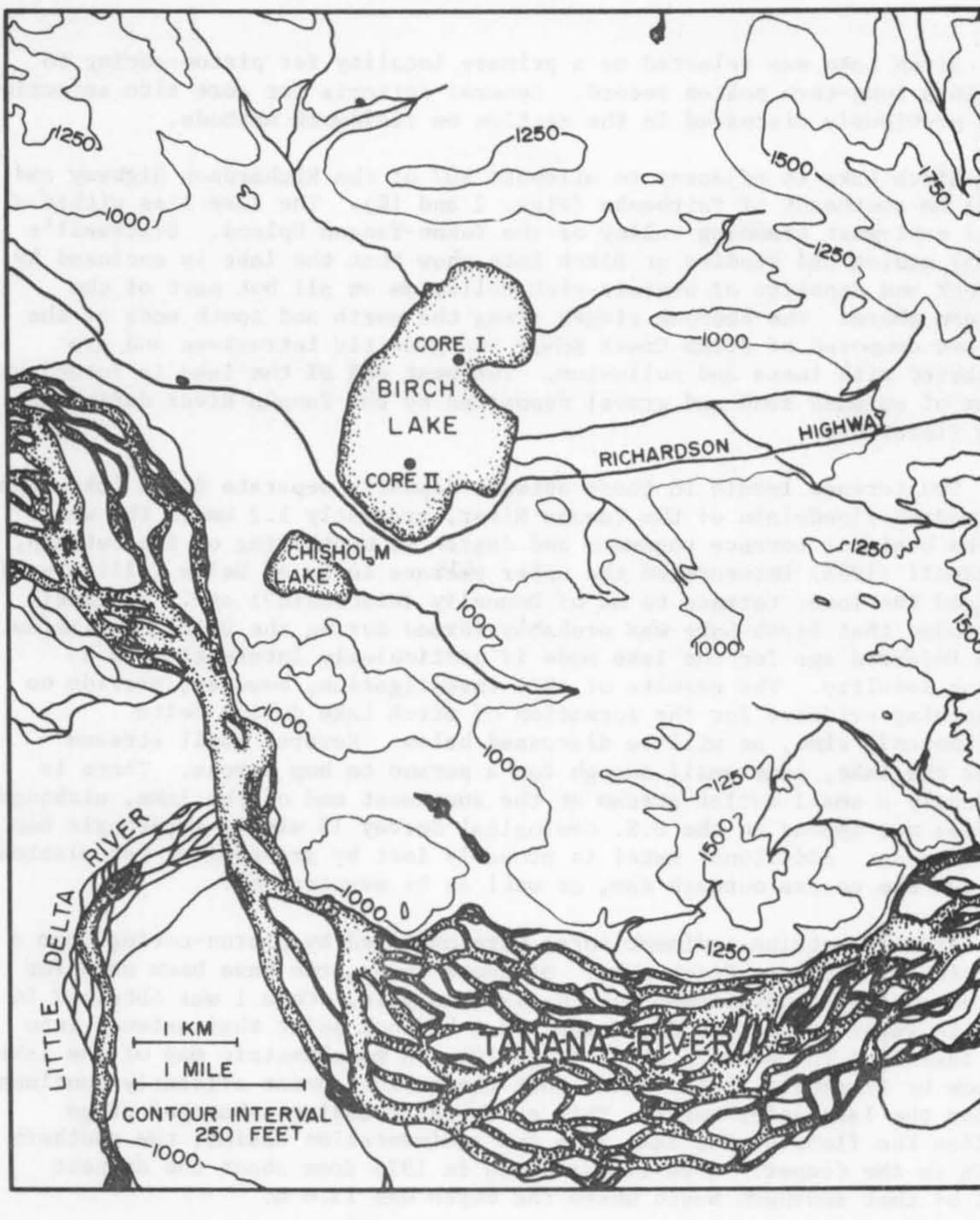

Fig. 10. Map of Birch Lake area.

and early Holocene. Loess deposits are very widespread in the Tanana Valley and adjacent uplands (Péwé, 1965, 1968). Much of this eolian silt falls on ridges and upper slopes of the upland and is retransported onto lower slopes and valley bottoms, incorporating organic material and often forming thick perennially-frozen deposits of organic-rich colluvium (Péwé, 1966). Most of the silty sediments in Birch Lake and other Tanana Valley lakes is interpreted to have been derived from loess, both as direct deposition into the lake and as reworked and retransported silt from the surrounding hills. Descriptions of dredged samples of uppermost Birch Lake sediments by Blackwell (1965) show that the surface sediment type in most of the lake is organic silt. The inorganic component has a sediment grain size and mineralogy similar to the loess which blankets the area (Péwé, 1965, p. 44). Blackwell's dredge samples from the lake bottom near the western shore of the lake contain mixtures of silt, sand, and gravel. The rock types in the gravel indicate that it was derived from outwash sediments transported into the lake basin by the Tanana River rather than from local bedrock sources.

Deeply weathered quartz-mica schist and granitic bedrock in the lake area also contributes sediments to the lake. The several small streams entering the lake flow through silty colluvium and, therefore, probably contribute small volumes of silt and organic debris. The slopes surrounding the lake are presently vegetated by mosaic forest, with ground cover of Equisetum, mosses, and heaths. Nevertheless, slope wash, especially during snowmelt, probably transports sediments downslope, and some of it enters the lake. Slopewash and gullying would probably be accelerated following fires which periodically sweep the upland forests. Swain's study (1973) of a varved lake-sediment core from northeastern Minnesota shows that varve thicknesses tend to increase following local fires. Therefore it is likely that the sedimentation rate increased temporarily in Birch Lake after local fires as well.

Biological activity within the lake also contributes organic material to the sediment. Diatoms and remains of algae such as Pediastrum, Botryococcus, and Chara have been identified from many core samples, and the remains of the abundant aquatic vascular plants that fringe the lake also contribute to the organic component of the sediment, along with leaves and forest litter from the surrounding vegetation.

Radiocarbon Dates

Six core segments from Birch Lake Core II and one from Birch Lake Core I were submitted for radiocarbon assay (Table 1). Samples were selected to coincide whenever possible with pollen zone boundaries, so that an absolute chronology could be established for regional vegetational changes. Intermediate samples were selected in Core II so that sedimentation rates could be calculated over shorter invervals of time (Table 2).

Core I

Lab Number	Core Interval	Radiocarbon Date 5568 Yr Half-Life	C^{13}/C^{12} Normalized Age
AU	244 - 270 cm	10,907 ± 513	no data

Core II

Lab Number	Core Interval	Radiocarbon Dates 5568 Yr Half-Life	Radiocarbon Dates 5730 Yr Half-Life	C^{13}/C^{12} Normalized Age
I-8064	80 - 90 cm	4,035 ± 135 B.P.	4,153 ± 135 B.P.	3,955 years B.P.
I-8065	128 - 142 cm	5,730 ± 130 B.P.	5,897 ± 130 B.P.	no data
I-8066	233 - 247 cm	8,450 ± 150 B.P.	8,696 ± 150 B.P.	no data
I-8070	288 - 300 cm	9,185 ± 325 B.P.	9,452 ± 325 B.P.	9,080 years B.P.
I-8067	385 - 400 cm	13,010 ± 500 B.P.	13,388 ± 500 B.P.	no data
I-8068	510 - 530 cm	14,730 ± 830 B.P.	15,158 ± 830 B.P.	14,700 years B.P.

TABLE 1: BIRCH LAKE RADIOCARBON DATES

TABLE 2

SEDIMENTATION RATES FROM BIRCH LAKE CORE II

Core interval	Time interval in radiocarbon years*	Mean sedimentation rate
0-85	0-4154 B.P.	48.87 yrs/cm
85-135 cm	4154-5897 B.P.	34.86 yrs/cm
135-240 cm	5897-8696 B.P.	26.65 yrs/cm
240-294 cm	8696-9452 B.P.	14.00 yrs/cm
294-392.5 cm	9452-13,388 B.P.	39.90 yrs/cm
392.5-520 cm	13,388-15,158 B.P.	13.88 yrs/cm
520-570 cm	15,158-15,852 B.P.**	13.88 yrs/cm**

* 5730 year half life

** estimated

Several samples were analyzed to assess possible hard water effects upon the dates (Table 1). The adjustments in dates suggested by $^{13}C/^{12}C$ analysis are rather trivial, however, and because not all samples had been analyzed to permit such adjustments, the adjusted dates were not used to calculate sedimentation rates. The hard water effect was evidently slight at Birch Lake, as far as can be determined from analysis. By extrapolating from the lowermost radiocarbon dates in the cores, an estimate of the age of the base of each core can be obtained. Thus Core I is roughly 12,000 years old and Core II is about 16,000 years old at the base of the pollen-bearing section of the core.

Sediment Stratigraphy

Sediment analysis of core segments from Birch Lake Cores I and II yields data which can be related to sedimentation processes in different parts of the lake basin. Core I sediments from relatively shallow water were deposited over approximately the same time interval as the upper 3.5 meters of Core II from deeper water. These comparable core sediments are quite similar in silt and clay content (Figs. 11 and 12). In Core I silt content is 76.2 to 88.3%; clay content is 7.5 to 19.6%. The upper 3.5 meters of Core II sediments is composed of 83.0 to 97.5% silt; clay content is 2.5 to 17.0%.

They differ more significantly in sand and organic sediment content, however. Core I samples contain 3.5 to 12.1% sand-size sediments, whereas most samples from the upper 3.5 meters of Core II contain no sand. The higher sand content in Core I samples is related to the relative proximity of the core site to shore and the shallow water depth. The deeper water site from which Core II was raised is relatively remote from sources of coarse sediments (Fig. 10). Organic content of the sediments from shallow water is lower than the sediments from deep water (Figs. 11 and 12). Core I sediment samples contain only 1.6 to 3.5% organic materials by dry sample weight, whereas samples from the upper half of Core II contain 3.2 to 17.1% organic material. The differences in organic content between the two core sites is also probably related to water depth. Sediments from shallow water sites are more likely to be subjected to oxidation than deep water sites. Core II sediments contain 3% or less organic material in the portion of the core below 3.5 meters. Clay content is also lower (less than 4%) in the interval 3.5 to 5.8 meters of the core. Perhaps during the interval represented by that core section, nearly all the sediment entering the lake was loess.

It was difficult to penetrate the lowermost 30 cm of Core II sediments. While the final section was being raised, some of the coarse sediments from the bottom of the core were lost. Enough was retrieved, however, to define the nature of the sediments encountered below the six meter level of the core. At 5.6 meters in the core, the silt becomes coarser and grades into mixed micaceous sand and silt at about 6.1 m.

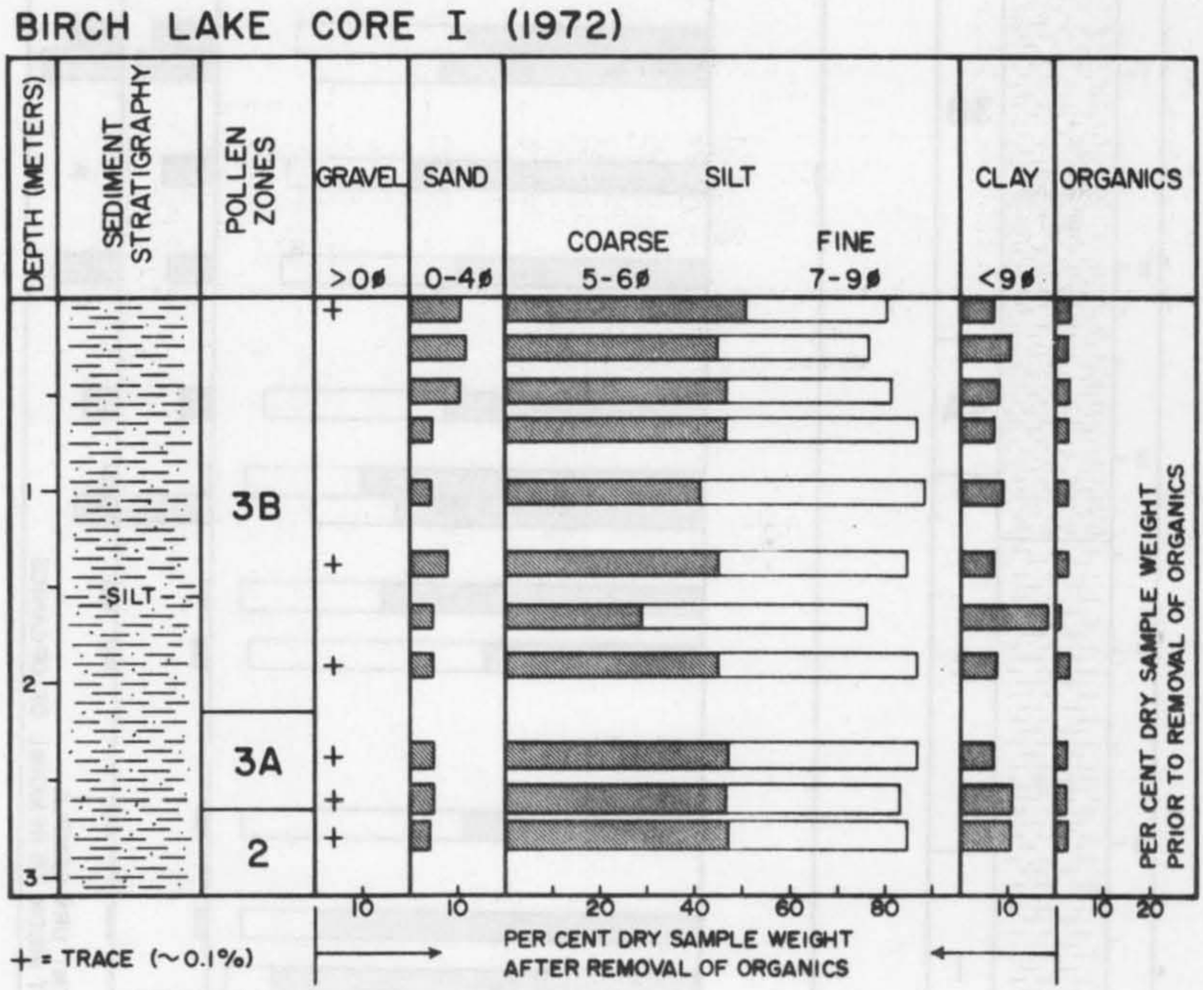

Fig. 11. Sediment Analysis Diagram for Birch Lake Core I.

BIRCH LAKE CORE II (1973)

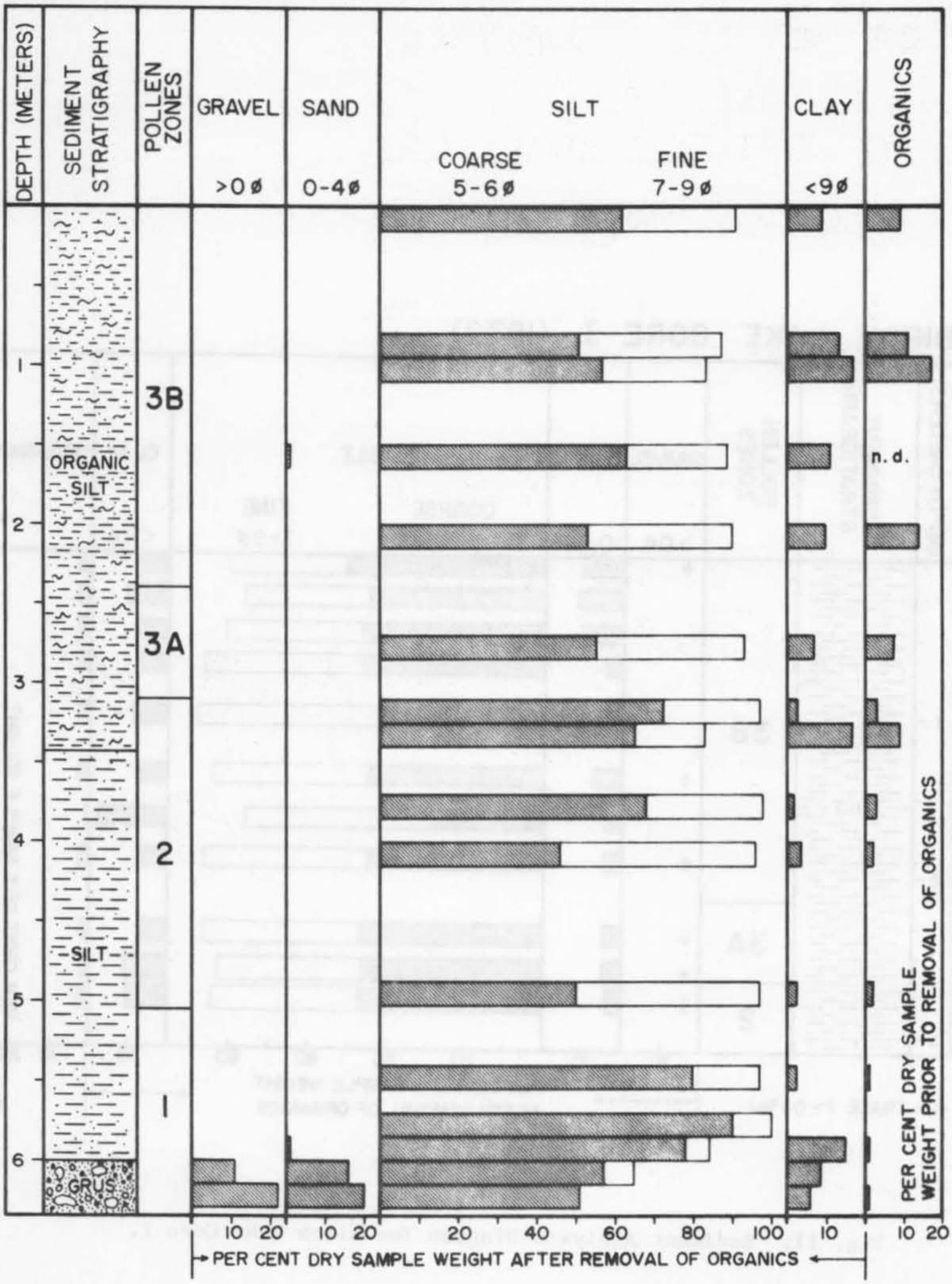

Fig. 12. Sediment Analysis Diagram for Birch Lake Core II.

This sand-silt layer grades into grus, a coarse, angular micaceous sand and gravel in a matrix of silt and clay derived from weathering of local granitic bedrock. It is likely that the grus encountered rests on bedrock at the coring site. The grus becomes coarser with depth, and the corer could not penetrate deeper, even with its steel cutting-bit. Because the core site is far from shore and in the deepest part of the lake, it seems unlikely that the grus encountered is simply a coarse layer of sediments deposited on top of still older sediments. That possibility cannot be excluded, however.

The mineral composition of the grus and the angularity of its grains rule out the possibility that it represents outwash gravel. It is likely that Birch Lake Core II spans the entire sediment column overlying bedrock in Birch Lake, at least in the southern sedimentation basin.

The stratigraphy and grain-size analysis of Birch Lake sediments suggest the following history of events. Granitic bedrock underlying the lake was deeply weathered in a subaerial environment over some unknown period prior to the formation of the lake, and a layer of coarse grus accumulated over bedrock. The grus was later buried by coarse silt, probably of eolian origin. The sediments in the lowest 0.5 m of Birch Lake Core II contain almost no pollen or spores and general organic content is extremely low. This suggests that the sediments may have been deposited in a subaerial environment or later exposed to one, which would result in oxidation or organic material contained in them. Sedimentation rates calculated from radiocarbon-dated core segments suggest that the periods of most rapid sedimentation were from 14,700 to 13,000 years B.P. and from 9200 to 8500 years B.P. These episodes of rapid sedimentation may be related to time intervals when outwash plains were closer to the lake or more extensive than at other times. These conditions could result in more abundant supplies of loess to be deposited in the lake area. The latter interval of rapid sedimentation is somewhat difficult to explain by that mechanism, however, because pollen evidence suggests that the region had become forested by that time, and the area covered by barren floodplains was probably smaller than during the preceding several thousand years. The 9200 year date may be too young, which would result in erroneous sedimentation rates for adjacent core intervals. A second date from an approximately comparable interval from Core I is 10,907 ± 500 years (Table 1).

Absolute Pollen Influx Data

Birch Lake Core II was processed to yield Absolute Pollen Influx data (hereafter referred to as API) using the methods previously described. The interpretations based upon API data from Birch Lake Core II are tentative for several reasons. First, the radiocarbon dates (Fig. 13)

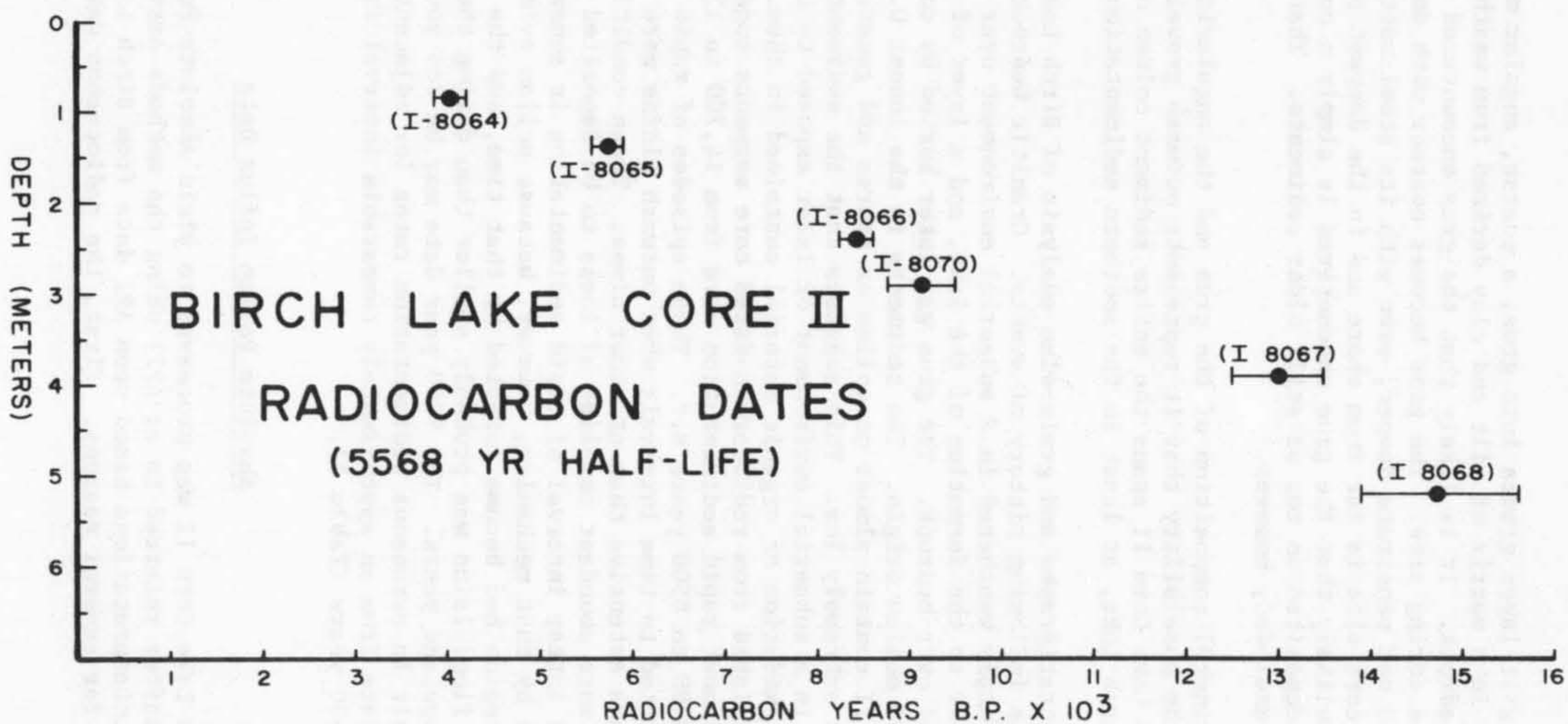

Fig. 13. Radiocarbon dates from Birch Lake Core II.

are more widely spaced than is preferred. This means that sedimentation rates must be assumed constant over considerable intervals of time between dated samples. If a significant change in sedimentation rates did occur between two dated intervals of the core, this would result in artificial or exaggerated changes in API for that interval. Second, there was no basal radiocarbon date from the core which would permit calculation of the sedimentation rate over Zone 1 samples. An assumed sedimentation rate of 13.88 years per cm was used to permit an approximate calculation of API for Zone 1 pollen samples. The assumed sedimentation rate was derived from the overlying radiocarbon-dated interval (392 to 520 cm). That sedimentation rate is the most rapid rate calculated for the core (Table 2). If the sedimentation rate was slower than the assumed rate, the calculated API for Zone 1 samples will be exaggerated. Pollen data from Birch Lake Core II was also calculated to provide a percentage diagram (Fig. 14). The API of major elements of Birch Lake Core II pollen spectra is displayed in a separate Absolute Influx diagram (Fig. 15). Calculations of sedimentation rates from Birch Lake Core II are based upon the 5730 year half-life for ^{14}C, rather than the less accurate 5568 year Libby half-life which is traditionally used when reporting radiocarbon dates. Interpretations of API data are incorporated in the following sections.

Pollen Assemblages

All pollen spectra of core subsamples from Birch Lake can be placed into one of three broadly defined but distinct pollen assemblages. Groupings of subsamples with similar pollen assemblages provide the basis for subdividing Birch Lake Core II into three major pollen zones. Pollen Zone 3 is further subdivided into two subzones, A and B. Some or all of these pollen zones can be recognized in all the other cores analyzed thus far in this investigation, and they occur in the same stratigraphic order in all cores. Birch Lake Core I (Fig. 16) includes only Zones 2 and 3.

Zone 1: Gramineae-Artemisia-Salix-Cyperaceae Assemblage

This assemblage is characterized by pollen spectra with no more than a few percent of spruce, alder, and birch pollen and high percentages of grass and *Artemisia* pollen. This combination of low percentages of tree and shrub pollen with high percentages of herbs resembles Pollen Zone I of Livingstone (1955) from northern Alaska. A major difference is that Livingstone's Zone I spectra contain much less *Artemisia* pollen.

In Zone 1, willows and sedges contribute significantly to the spectra. Commonly present minor elements include *Plantago*, various Compositae and Rosaceae (especially *Potentilla* sim.), Chenopodiaceae, and Caryophyllaceae. The only samples with this type of pollen spectra come from lowermost pollen-bearing sections of Birch Lake Core II and the Lake George Core (Figs. 12, 26).

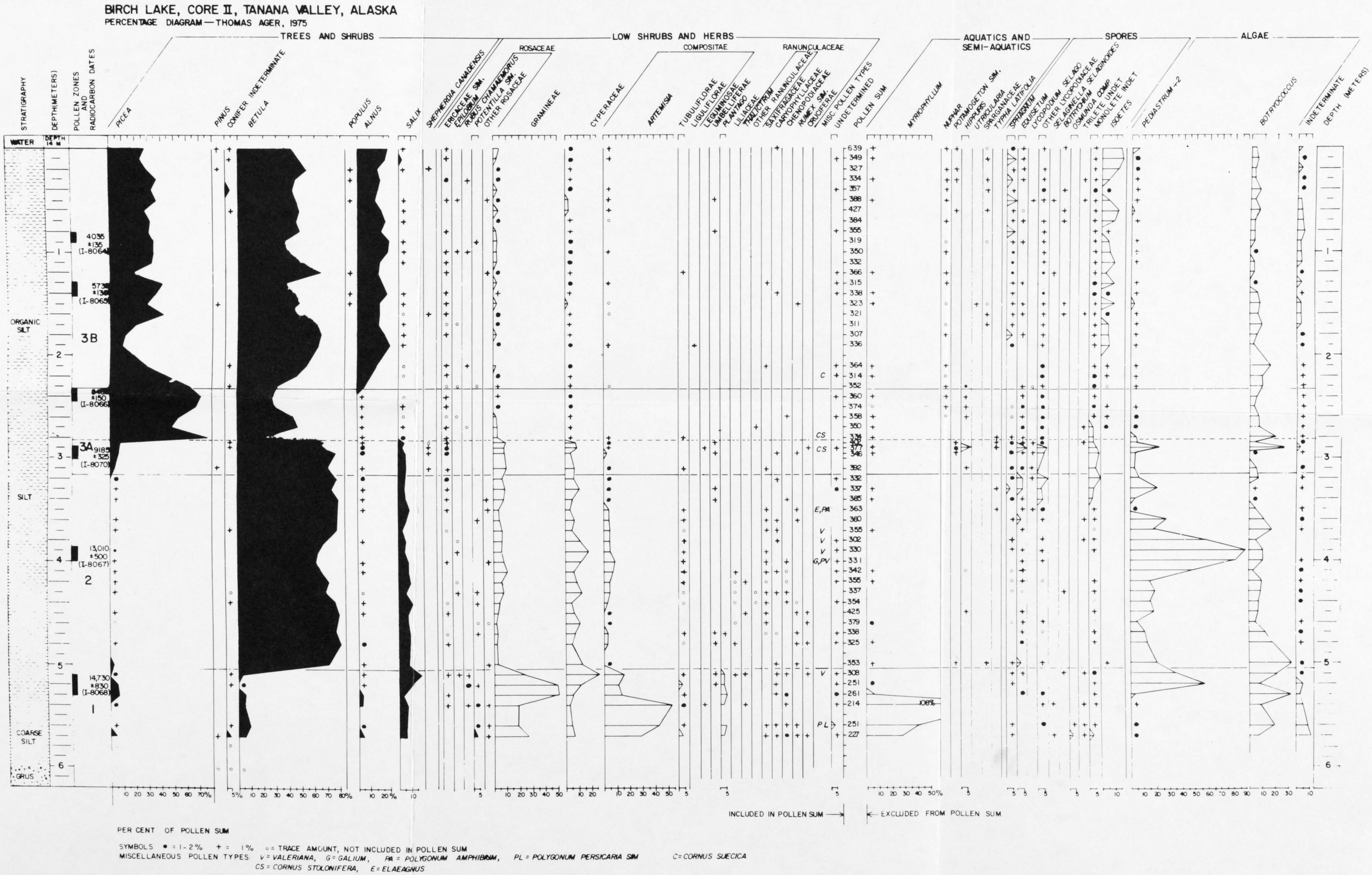

Fig. 14. Pollen percentage diagram, Birch Lake Core II.

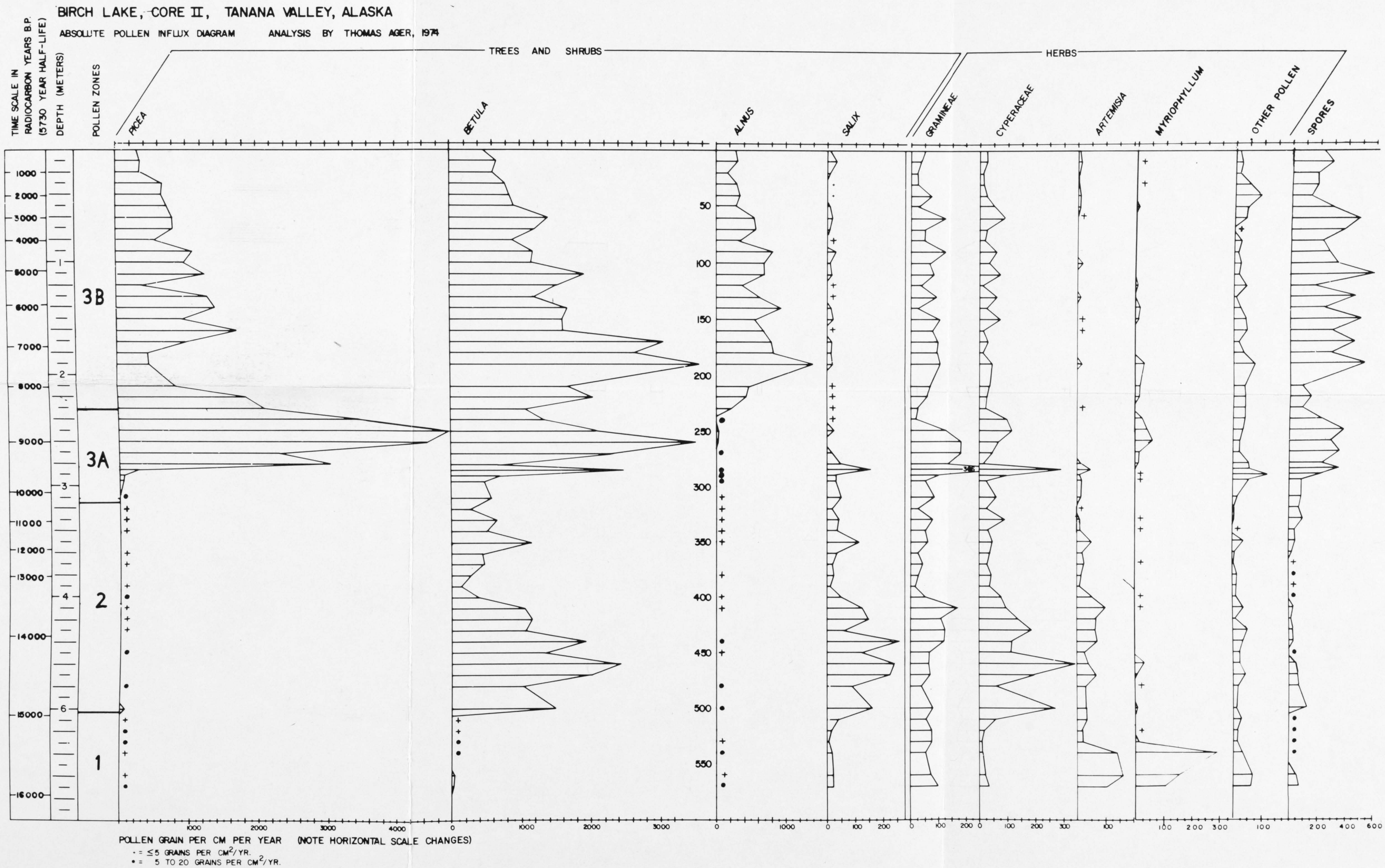

Fig. 15. Absolute Pollen Influx Diagram, Birch Lake Core II.

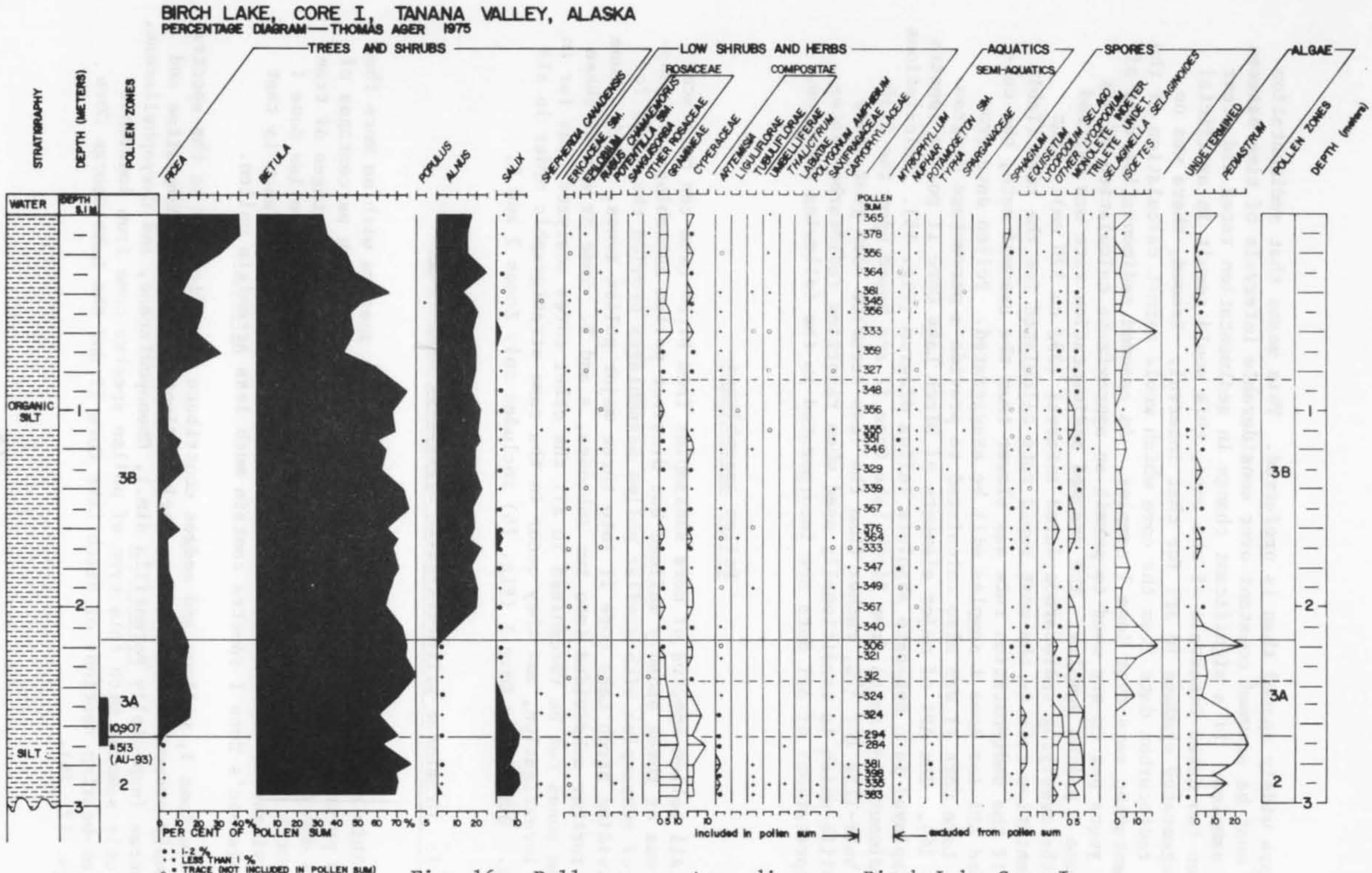

Fig. 16. Pollen percentage diagram, Birch Lake Core I.

Zone 2: Betula-Salix-Gramineae-Cyperaceae Assemblage

Pollen spectra assigned to this assemblage are overwhelmingly dominated by birch pollen and contain very low percentages of spruce and alder pollen. This assemblage closely resembles Zone II from northern Alaska (Livingstone, 1955). Willows, grasses, and sedges are also important contributors to this pollen assemblage. The birch species contributing all, or nearly all, of the Betula pollen in this assemblage are probably dwarf birch (Betula nana) and, perhaps, resin birch (Betula glandulosa) rather than tree birches. This assumption is based upon comparisons between Zone 1 pollen spectra and surface pollen spectra from areas of shrub tundra (e.g. Colinvaux, 1964, 1967a; Birks, 1973) and on the near absence of spruce and alder in these samples. Environmental factors that prevented spruce and alder from surviving are likely to have eliminated paper birch trees (Betula papyrifera) as well.

Birch pollen percentages are consistently high in all samples assigned to this assemblage (Figs. 14, 16, 26).

Zone 3; Subzone 3A: Picea-Betula Assemblage

In the pollen assemblage of Subzone 3A, 2 to 80% of the pollen sum is spruce pollen, and in most samples 20 to 75% of the pollen sum is birch pollen. Subsamples from Birch Lake cores I and II and Lake George Core I yielded pollen spectra assigned to this subzone. Subzone 3A pollen spectra generally include up to 12% willow, 10% sedge, and 10% grass pollen.

Zone 3; Subzone 3B: Picea-Betula-Alnus Assemblage

The Subzone 3B pollen assemblage is characterized by spruce pollen (generally more than 10% of the pollen sum), birch pollen (30 to 80% of the pollen sum) and alder pollen (up to 25% of the pollen sum). Pollen of grass, sedge, willow and Artemisia occur in Subzone 3B spectra, but usually in small amounts, except in localities such as Healy Lake where local vegetation influence is strongly reflected in the pollen spectra (Fig. 20). Two minor elements, Nuphar and Isoëtes, tend to be restricted to this assemblage, but are not found in all samples. The latter two plants are restricted to aquatic habitats.

Vegetational Interpretation of Zone 1 Pollen Assemblage

Quaternary palynologists often compare fossil pollen spectra with modern spectra collected from known vegetation types as an aid in interpreting past vegetation types. This vegetational analog method is most likely to be successful in regions such as Alaska where the modern vegetation is relatively undisturbed by man and can therefore serve as potentially valid analogs. There are several limitations of the analog method however. The published data on modern pollen spectra in Alaska are inadequate to provide a full range of possible comparisons with fossil pollen data (e.g. Matthews, 1970; Colinvaux, 1967a). That limitation is perhaps not too serious, however, because supplemental data on modern pollen rain from western Canada can be used (e.g. Rampton, 1971a; Lichti-Federovich and Ritchie, 1965, 1968; Terasmae, 1967a).

Another problem with the analog approach is the taxonomic levels of identification possible in routine pollen analysis. Many pollen types can be identified to family or genus level; few can be identified to species level. Consequently, only broad comparisons between fossil and modern pollen assemblages is possible. This becomes a serious limitation when pollen spectra are dominated by grasses and sedges which are identified to family level, because each family includes many species with very different habitat requirements. An additional serious limitation of analogs is the fact that many past vegetation types seem to lack modern vegetational counterparts (Wright, 1971).

Comparisons between Zone 1 pollen spectra (Fig. 14) and available modern pollen spectra suggest that no close modern analog for Zone 1 vegetation exists in North America. Zone 1 pollen spectra do share some traits however, with pollen spectra from some types of herbaceous tundra and grasslands of North America, and from some possible remnant steppe-tundra vegetation in Siberia.

Surface pollen samples from near Barrow in northern Alaska (Livingstone, 1955) have similarly herb-dominated pollen spectra with abundant grass and sedge pollen and low percentages of spruce, alder, and birch pollen. Artemisia is absent from the Barrow samples, however, and sedge percentages are higher than in Zone 1 samples. The modern vegetation at Barrow is wet, herbaceous, tussocky tundra. Sedges are a very important component of the vegetation. Barrow's mean annual temperature is about -12°C, and in spite of an annual precipitation of only about 10 cm, there is an excess of moisture over evaporation. Zone 1 produces spectra that more closely resemble spectra from contemporary grasslands in western Canada (Lichti-Federovich and Ritchie, 1968; Birks, 1973). The Canadian grassland spectra contain much higher percentages of Chenopodiaceae, arboreal pollen, and different minor elements; but nevertheless, the similarity is striking. The vegetation that produced Zone 1 pollen spectra was neither a Barrow-type herbaceous tundra nor a Canadian-type grassland, but may have included elements of both. It is evidently a vegetation which no longer exists in North America but has possible near-analogs in the Siberian steppe or steppe-tundra.

Mountain steppe and "steppe-tundra" vegetation exist today in scattered localities near Lake Baikal and elsewhere in Siberia (Budyko, 1974; Grichuk, 1964; Vaskovskiy, 1964; Giterman, 1973). Budyko (1974) defines an area centered at about 63°N latitude and 125°E longitude which he characterizes as Siberian steppe. Other vegetation maps of Siberia show the same area as boreal forest, however (Walter, 1973, p. 192). Paleobotanical data and modern phytogeographical data from Siberia suggest that steppe-tundra vegetation was much more extensive in Siberia during late Pleistocene glaciations and indeed may have extended across the Bering Land Bridge to the Yukon-Tanana basin of interior Alaska (Tomirdiaro, 1973; Hopkins, 1972). Giterman (1973) reconstructs the full glacial vegetation of Beringia as a combination of tundra, tundra-steppe, meadow tundra, steppe, and hypoarctic associations in a periglacial landscape.

The steppe-like vegetational remnants in Siberia include elements of eastern European steppes, Mongolian steppes, and high alpine vegetation. This suggests that during past glaciations these separate floras expanded their ranges and combined to form widespread steppe-tundra vegetation in Siberia (Grichuk, 1964).

The flora of the remnant steppe-like areas of modern Siberia varies from area to area, but are generally characterized by abundant grasses and <u>Artemisia</u>. Some characteristic elements of certain Siberian and Mongolian steppe floras such as <u>Ephedra</u> and <u>Selaginella sibirica</u> have not been found in the Zone 1 pollen record from the Tanana Valley (Vaskovskiy, 1964; Giterman, 1973). Modern steppe-like vegetation nevertheless provides a probable near-analog for Zone 1 vegetation.

Several previous investigators in Alaska have interpreted paleobotanical evidence to indicate the Beringian vegetation of late Wisconsin age had a steppe-like character (Colinvaux, 1964; Colbaugh, 1968; Matthews, 1974a, 1974b; Hopkins, 1972). Abundant pollen of <u>Artemisia</u> and grass is a common feature of such sites. The Tanana Valley pollen records contain some of the highest percentages of pollen of grass and <u>Artemisia</u> pollen yet found in Alaska, which makes a steppe-tundra interpretation less speculative than in previous studies.

<u>Climatic Interpretation of Zone 1 Pollen Record</u>

The general relationship between climate and vegetation is manifested by the earth's broad latitudinal "zones" of vegetation. The precise mechanisms controlling these relationships between climate and vegetation are still poorly understood, however. Recent investigations have begun to define some of these relationships more clearly, such as the relationship between climate and the position of the boundary between boreal forest or taiga and tundra (Hopkins, 1959; Bryson, 1966; Larsen, 1971; Hare and Ritchie, 1972).

The complexity of the climate-vegetation interaction is discussed by Walter (1973) and Budyko (1974). They emphasize the fact that the amount of soil moisture is more critical than the amount of precipitation which falls. This is particularly important in areas where permafrost lies near the surface and a perched water table is maintained above it. In spite of the complexity of climatic-vegetational relationships, it is possible to infer general aspects of paleoclimate from the vegetational assemblage. Attempts to reconstruct detailed paleotemperature and other climatic parameters rest upon shakey foundations when dealing with high latitude vegetation as climatic indicators. Vegetation can change in response to several climatic and other variables in the environment, and it is difficult to interpret which parameters caused what change. In addition paleoclimatic reconstructions based upon paleobotanical evidence rely upon present-day knowledge of the ecological requirements of the plants involved. Too often we discover that so called indicator species mislead us because the ecological requirements are often not well understood, particularly in the case of arctic and subarctic plants. Aquatic plants can be particularly misleading indicators of climate (see, for example Seddon, 1967). Such aquatic plants from the study area as Polygonum persicaria, P. amphibium, and Typha latifolia are seemingly restricted to forested parts of Alaska and Yukon Territory. Pollen of those plants can be found in late Wisconsin sediments in a tundra setting, however (Fig. 14, 16). Macrofossil evidence from Isabella Basin also provides evidence that the range of habitats of some plants are greatly underestimated.

The major vegetational changes represented by the pollen records from the Tanana Valley do provide some insight into probable climatic conditions during the past 16,000 years. Zone 1 is dominated by grasses and Artemisia, plants which are favored over shrub or forest vegetation under xeric conditions. Shrubs and trees are eliminated under arid conditions as soil moisture decreases and transpiration potential declines (Budyko, 1974, p. 364).

Although the Siberian "steppe" and mountain steppes are not perfect analogs for Zone 1 vegetation, the climate of such areas of Siberia today provides some insight into possible climatic conditions of interior Alaska during late Wisconsin time prior to 14,000 years ago. Siberian steppe or steppe-like areas have exceedingly severe winters with mean January temperatures generally at or below -32°C. Present-day winters in interior Alaska are quite severe also, but mean January temperature is closer to -23°C. Snowfall in steppe-like areas of Siberia is light, and tends to form a thinner wind-swept layer than forms in forested interior Alaska. Whereas both tundra and taiga vegetation have an excess of moisture over potential evaporation, steppe-like areas are dry, with potential evaporation exceeding precipitation by a factor of about 1/1 to 3/1 (Budyko, 1974, p. 360).

The climatic analog provided by Siberian steppe remnants is generally consistent with climatic models proposed for interior portions of Beringia during full-glacial conditions (Streten, 1974; Sergin and Shcheglova, 1973; Péwé, in press; Hopkins, 1972). The evidence points to an extremely continental climate, which is related to eustatic lowering of sea level and exposure of the broad expanse of the Bering Land Bridge. That event alone would reduce the amount of moisture reaching interior Alaska from the Bering Sea and North Pacific. The development of extensive ice-fields in the mountains south and southwest of the Tanana Valley probably increased the effectiveness of the mountain ranges as barriers to warmer moist air from the North Pacific (Streten, 1974).

Winters were much colder than at present in the Tanana Valley, and summers were shorter but warm during late Wisconsin time. Annual precipitation was probably less than half of that which falls today. Permafrost was evidently continuous, or at least much more widespread than at present (Péwé, 1966a; in press), but it is likely that the permafrost table was not close enough to the surface to maintain a high water table.

Implications for history of formation of Birch Lake

According to Blackwell (1965) and Péwé (1965) Birch Lake and other major lakes in the Tanana Valley were probably formed during the Delta (Illinoian?) Glaciation. That interpretation is based in large part upon tentative correlation of the fluvial terrace sequence in the middle Tanana Valley with the two-fold Delta-Donnelly glacial sequence in the Alaska Range.

Pollen data from Zone 1 of Birch Lake Core II suggests a different chronology of lake formation. The lower 0.5 m of pollen-bearing sediments of the core contain very high percentages (up to 108%) of pollen of the aquatic plant Myriophyllum (Fig. 14). In the overlying sediments of Core II and in all other cores examined Myriophyllum pollen is generally less than 2% of the pollen sum. Such high percentages of Myriophyllum pollen in Zone 1 from Birch Lake can be satisfactorily explained only if the plant were growing in the immediate vicinity of the core site. Since Myriophyllum is restricted to shallow water environments (Hultén, 1968), I conclude that at the time of its abundance only a shallow tundra pond existed at the site of present-day Birch Lake.

A sharp decrease in the percentage of Myriophyllum pollen in the sediment at depths of 5.3 to 5.4 m is followed by an increase in the percentage of sedge and grass pollen, a temporary slight increase in spruce pollen, and a decrease in Artemisia pollen. All these trends suggest that lake level was rising rapidly, flooding the tundra pond and the surrounding area about 15,000 radiocarbon years ago. Pediastrum colonies also become very abundant during this inferred rise in lake level. At least some species of Pediastrum seem to be most abundant in shallow lakes in arctic Alaska (Colinvaux, 1967b). Pediastrum was not identified to species level in this study. Therefore, the significance of the fluctuations of Pediastrum concentrations in the lake is uncertain. A rise in lake level would explain not only the decrease in Myriophyllum percentages about 15,000 years ago but also the simultaneous slight increase in spruce pollen percentages which can be seen in upper Zone 1 (Fig. 14). No such spruce pollen increase occurs in Zone 1 from Lake George. Therefore it is unlikely that the spruce pollen increase at Birch Lake reflects any vegetational change in the region. It is most likely that the temporary increase in spruce pollen percentages in upper Zone 1 is the result of reworking older pollen-bearing sediments. Perennially frozen colluvium of Sangamon and Mid-Wisconsin age are known to contain pollen of spruce in interior Alaska (Matthews, 1970; 1974a; Péwé, in press). As lake level rose, frozen valley-fill sediments began to thaw and pre-late Wisconsin age pollen was mixed with contemporary pollen in the lake.

This interpretation of the history of lake formation implies that Birch Lake has been in existence for only about 15,000 years rather than since the Delta (Illinoian?) glaciation.

The nature of the sediments (grus) at the base of the core suggests that the sediment record penetrates to weathered bedrock. It is possible but unlikely that the grus is only a layer overlying still-older lacustrine sediments. If the outwash sediments which originally dammed the lake basin are indeed of Delta age, then the theoretical Delta-age lake was later drained. Its sediments were buried under grus or eroded from the core site prior to the formation of the present lake about 15,000 years ago during late Wisconsin time.

A critical re-examination of the outwash terrace sequence would be justified in view of the pollen evidence from Birch Lake. It is possible the terraces are younger than previously believed. It would also be useful to core the sediments of several Tanana Valley lakes to bedrock to resolve the question of when the lakes were first formed.

Vegetational Interpretation of Zone 2 Pollen Assemblage

Zone 2 pollen spectra resemble Zone II (Birch Zone) pollen spectra described from northern Alaska by Livingstone (1955) and modern pollen spectra from shrub tundra areas of Alaska and northwestern Canada (e.g. Colinvaux, 1964; Ritchie, 1972; Birks, 1973). Zone 2 pollen samples contain unusually high percentages of birch pollen, however, which suggests that shrub birches were considerably more abundant in the Zone 2 vegetation than in contemporary shrub tundra vegetation for which pollen data are available. Most modern pollen samples from shrub tundra sites, even sites far removed from trees, contain abundant pollen of spruce and alder and sometimes other arboreal pollen types. Long-distance transport by wind is responsible for the presence of arboreal pollen in such shrub tundra sites. The near-absence of spruce and alder pollen in Zone 2 samples, therefore strongly suggests that those plants were absent from the Tanana Valley region during Zone 2 time.

The Zone 2 vegetation was composed of shrub birch (*Betula nana*, *Betula glandulosa*), willows, sedges, heaths, some grasses, and a small amount of *Artemisia*. Heaths are poorly represented in the lacustrine pollen records, but it is likely they were an important component of the vegetation in Zone 2 time. It is likely that sedge tussocks of cotton-grass (*Eriophorum*) were a common feature in Zone 2 shrub tundra, as they are today. *Artemisia* probably persisted in restricted xeric habitats such as on barren outwash sediments of the floodplains and steep south-facing slopes. *Artemisia frigida*, *A. telesii*, *A. alaskana*, and *A. arctica* still can be found growing in such dry habitats in the Tanana Valley today (Hultén, 1968).

Pollen percentages vary only slightly throughout Zone 2, which suggests considerable stability of the vegetation between 14,000 and 10,000 years ago. Absolute Pollen Influx data (Fig. 15) suggests a drop in pollen influx rates about 13,000 years B.P., however. The significance of the drop is uncertain and may indeed be an artificial decrease resulting from a change in sedimentation rates within a radiocarbon date-bracketed interval. Evaluation of this possible decrease in pollen influx will be deferred until other cores from the region can be analyzed for API over the same interval of time.

Pollen Zone 2 was deposited during approximately the same time interval as Rampton's (1971a) Pollen Zone 3b from Antifreeze Pond in southwestern Yukon Territory. The pollen data suggest that a different type of vegetation existed near Antifreeze Pond at the time when shrub tundra covered much of the Tanana Valley. Zone 3b from Antifreeze Pond suggests a sedge-dominated vegetation which included grasses and various herbs but only a small amount of dwarf birch. These differences in vegetation are most likely to reflect altitudinal zonation of vegetation. Antifreeze Pond is several hundred meters higher above sea level than sites cored in the Tanana Valley.

It is more difficult to compare Zone 2 from the Tanana Valley with the pollen record obtained from the valley fill at Isabella Basin near Fairbanks (Matthews, 1974a). Zone 2 is very roughly comparable to the upper half of Zone B from Isabella Basin. The radiocarbon dates do not agree closely, however, and there are significant differences in pollen spectra between the lacustrine cores and the valley-fill sediments. Upper Zone B from Isabella displays much higher percentages of Artemisia and much lower percentages of birch pollen than do Zone 2 samples from the lakes. I suggest that the differences between pollen spectra of the sites do not necessarily imply major differences in vegetation types between lowland and upland sites. The differences in pollen spectra are probably due mostly to local vegetational influences at the Isabella site. Matthews (1974a) cites evidence that Artemisia was growing at the core site during Zone B time. That may account for high Artemisia percentages at Isabella at a time when the regional vegetation was shrub tundra. It is also possible that differential preservation of pollen and reworking of older sediments contributed to the high Artemisia percentages in upper Zone B. It is important to point out, however, that the Isabella record suggests a persistence of steppe-like conditions in interior Alaska until about 8500 years B.P. (Matthews, 1974a). The pollen record from lakes suggests, however, that the steppe-tundra environment ended 14,000 years ago, and only certain elements of steppe-tundra vegetation persisted in restricted habitats during Zone 2 time.

Climatic interpretation of Zone 2 pollen record

The abrupt transition from steppe-tundra to shrub tundra vegetation about 14,000 years ago suggests an rapid climatic shift to warmer, moister conditions. Geological evidence from other areas of Alaska and Yukon Territory also suggests a climate change to warmer conditions about 13,500 to 14,000 years ago. Denton (1974) cites evidence for major glacier recession in the St. Elias Mountains about 14,000 years ago. Rampton's (1971b) study of glacial deposits in the Snag-Klutlan area of southwestern Yukon Territory suggests glacier recession occurred about 13,500 years B.P. Rampton's pollen diagram from the same area (1974a) shows a vegetation change from grass-dominated tundra to sedge-dominated tundra about 13,500 years B.P.

In the Brooks Range, glaciers changed from frozen-base to wet base roughly 14,000 years ago (T.D. Hamilton, pers. com. 1974).

Hopkins (1972) reviews evidence from western Alaska which suggests climatic change about 13,500 years ago. There is other evidence from Seward Peninsula, however, that suggests the transition from herbaceous tundra to shrub tundra did not occur until 12,000 years ago in western Alaska (Colbaugh, 1968; Matthews, 1974b).

These differences may reflect problems with some of the radiocarbon dates, or perhaps vegetation changes were not simultaneous everywhere due to differences in altitude, degree of maritime influences, or other factors.

No evidence for other climate changes within Zone 2 can be discerned from the pollen evidence. This does not necessarily imply that no changes occurred but only that the vegetation remained quite stable between about 14,000 and 10,000 years ago in the middle Tanana Valley.

Vegetational Interpretation of Subzone 3A Pollen Assemblage

Pollen Subzone 3A records the invasion and ultimate replacement of the regional shrub tundra by spruce-birch forest during early Holocene time. The progressive change in pollen spectra in Subzone 3A mirrors the progress of the vegetational transition. Lowermost Subzone 3A pollen spectra closely resemble Zone 2 spectra, except the former contain at least a few per cent spruce pollen. The low initial spruce pollen percentages and API from Birch Lake Core II would perhaps justify placing the Zone 2-3A boundary at the dashed horizontal line in the pollen diagram (Fig. 14). Other diagrams from the region display a steeper initial rise of spruce pollen percentages, however (Figs. 16, 26), and therefore the Zone 2-3A boundary has been placed at the point of initial increase of spruce pollen percentages.

Radiocarbon dates from Birch Lake cores (Table 1, Figs. 14, 16) suggest that the initial invasion of spruce occurred roughly 10,000 years ago. Trees probably spread initially throughout the region along rivers, where they formed gallery forests surrounded by shrub tundra. By about 9000 years ago, spruce-birch forest had replaced shrub tundra over much of the region,at least in the lowland.

There are a number of radiocarbon dates on late Quaternary wood samples from deposits in interior Alaska, and most of the dates are either of mid-Wisconsin age (> 25,000 years B.P.) or less than 10,000 years B.P. A few wood dates fall within the 10,000 to 11,000 year range, but very few wood types are identified and could therefore be derived from woody shrubs such as willows. One exception is a "conifer root" dated 11,000 ± 280 years B.P. (I-1370) (Péwé, 1975). It is most likely that only a few trees were present in the region prior to 10,000 years B.P.

Radiocarbon dates associated with the initial arrival of spruce pollen in interior Alaska and adjacent areas are 9100 years B.P. at Tangle Lakes, south of the Tanana Valley (C. Schweger, pers. com., 1973), 8700 years B.P. near Antifreeze Pond, southwest Yukon Territory (Rampton, 1971a), and about 8000 to 8500 years B.P. near Fairbanks (Matthews, 1974a).

Absolute Pollen Influx data (Fig. 15) from Subzone 3A suggest that a dramatic increase in accumulation rates of arboreal pollen occurred in the region about 9000 years B.P. While birch pollen percentages generally decrease in Subzone 3A from Zone 2 levels, API data suggest that the actual production of birch pollen was much higher. These increases in API during Subzone 3A suggest that spruce and tree birch became established simultaneously in the region. It is also likely that trees such as quaking aspen, balsam poplar, and larch also became established at that time, although they are unrepresented in the pollen record.

Climatic interpretation of Subzone 3A pollen record

In view of the range of radiocarbon dates (8000-11,000 years B.P.) associated with early invasion of spruce in the Tanana Valley and adjacent areas, it is still uncertain as to how closely the invasion coincides with climatic change to warmer conditions in latest Wisconsin-early Holocene time. It appears very likely that at least a few spruce were present in the region prior to 9000 years B.P. Additional radiocarbon dates will be required to more closely pinpoint the time of spruce invasion. More macrofossil evidence will be required to determine whether or not a few spruce somehow managed to survive in the interior throughout late Wisconsin time. Both questions must be answered before the relationship between the climatic and vegetational change can be fully assessed.

There are two alternate interpretations of the existing data. The first interpretation is that spruce did not survive in interior Alaska during late Wisconsin time, and therefore a time lag of unknown duration would be expected between the change in climate and the invasion of spruce from some distant refugium. Spruce appeared in the District of Mackenzie, Northwest Territories, between 11,000 and 12,000 years ago (Ritchie and Hare, 1971). This lends support to the idea that climatic conditions became suitable for spruce some time prior to its appearance in interior Alaska. It also opens the question as to whether or not spruce appeared in the District of Mackenzie by way of the corridor between the Laurentide and Cordilleran Ice Sheets in late Wisconsin time, rather than from a refugium in the interior of northwestern Canada or Alaska.

The alternate interpretation is that a few spruce did indeed survive in marginal habitats throughout late Wisconsin time in the interior. These few scattered populations of spruce then rapidly expanded their range as soon as climatic conditions permitted. If that scenario is correct, then the date of initial spruce expansion in interior Alaska may closely date the time of climatic shift to warmer conditions. The flaw in this interpretation is of course the lack of spruce pollen in late Wisconsin age sediments. Only traces of spruce pollen are present, and those traces can be accounted for by reworking of older sediments around the lake or long distance transport from sources several hundred kilometers away. Even if summer temperatures were adequate for the survival of spruce, the short growing season, and perhaps dry climate during Zone 1 time may have prevented their survival.

Hot springs in interior Alaska are possible sites where spruce survived in marginal microhabitats. Nava and Morrison (1974) report unusual vegetation near hot springs of the interor. Such sites could perhaps yield macrofossils of late Wisconsin spruce.

Although the date of the initial spruce invasion is still uncertain, it does appear that the interval of major spruce expansion in the middle Tanana Valley coincides roughly with the early Holocene warm interval (10,000 to 8000 years B.P.) recognized in northwestern and northern coastal Alaska (McCulloch and Hopkins, 1966; Detterman, 1970; Hopkins, 1972). This warming event does not seem to coincide with vegetation change in inland northwestern Alaska, however (Schweger, 1973).

Vegetational Interpretation of Subzone 3B Pollen Assemblage

The lower boundary of Subzone 3B is marked by an increase of alder pollen to more than the 0-2% found in Subzone 3A. This increase marks the arrival and expansion of alder in the region about 8400 radiocarbon years ago. The Subzone 3A-3B boundary also coincides with the beginning of a gradual decrease in spruce percentages which continued to decrease until about 7000 years ago. The 7000 year date is extrapolated from bracketing radiocarbon dates. The spruce decline is also reflected in API data (Fig. 15). Pollen percentages and API for birch display an increase which coincides with the spruce decline. This suggests that a substantial portion of the spruce trees in the region were replaced by birch trees during that interval. After about 7000 years ago, spruce pollen percentages increased until roughly 6500 years ago (extrapolated date) in Birch Lake Core II. Since that time, percentages of spruce and birch pollen have remained rather stable. It is likely, therefore, that the relative proportions of spruce and birch, and other constituents of the middle Tanana Valley forests, have undergone little change over the past 6500 years. The steady decline in API over that 6500 year interval may simply reflect higher water content of the sediments in the upper part of the core, which decreases the actual volume of sediment in the subsamples.

The diagram suggests that the API of willows decreased significantly in Subzone 3B, but grasses and sedges contribute about as much pollen as in the shrub tundra environment. The major source of this pollen of grass and sedge may be local shoreline and muskeg vegetation. Low API for Artemisia in Subzone 3B reflects a relative scarcity of suitable xeric habitats in the vicinity of Birch Lake during the past 8400 years.

Pollen spectra from Subzone 3B compare closely to modern pollen spectra collected from the lowland areas of the middle Tanana Valley. (Fig. 8).

Climatic interpretation of Subzone 3B pollen record

It is unclear as to whether or not the appearance of alder in the region 8400 years ago has any climatic significance. The arrival of alder does approximately coincide with an interval of alpine glaciation in the Brooks Range and Alaska Range (T.D. Hamilton, pers. com., 1974; Péwé et al., 1965). This may be coincidental, however, because alder arrived at different times in various parts of Alaska, which suggests gradual range expansion from various refugia. For example, there is evidence that alder was present in western Alaska 10,000 years ago (D. M. Hopkins, pers. com., 1974), but it was absent in northern Alaska until about 6000 years B.P. (Livingstone, 1955).

The decrease of spruce pollen percentages and API over the interval 8400-6500 years B.P. suggests possible climatic influence however. According to Flint (1971, p. 524), the Hypsithermal spans the broadly-defined interval 9000 to 2500 years B.P. Within that interval a number of climatic fluctuations have been recognized in northwestern North America and elsewhere (Denton and Karlén, 1973). Soviet scientists recognize a thermal maximum about 7000 to 6000 years B.P. (Kind, 1973) or about 8000 to 4500 years B.P. (Lozhkin, 1973). In northwestern Canada and non-coastal Alaska, the Holocene thermal maximum evidently peaked about 5000 years B.P. (Hopkins, 1972).

The spruce decline in the Tanana Valley perhaps reflects an interval of warmer, drier climate, but the chronology does not fit well with the 5000 year B.P. peak suggested by Hopkins (1972) because the spruce minimum occurred about 7000 years B.P. If the spruce decline is indeed related to climatic change, one possible cause for such a change is a substantial increase in the frequency of forest fires. During this century forest fires in interior Alaska have been most widespread during warm, dry summers (Viereck, 1973). If the interval 8000 to 6500 years B.P. was typified by unusually warm, dry summers in interior Alaska, fires would perhaps have been more frequent and sufficiently widespread to maintain a large portion of the regional forest in a state of early post-fire succession. Birch and aspen would thereby be favored over spruce. If left undisturbed by fire, spruce tends to eventually replace birch and aspen in upland sites (Viereck and Little, 1972). A return to moister summers about 6500 years ago would explain the increase in spruce at that time. This interpretation for the cause of the spruce decline is of course highly speculative. One alternative explanation for such a spruce decline is disease. Most diseases of spruce in Alaska tend to be most destructive in areas where fires have already damaged the forests, however (Viereck, 1973).

The stability of pollen percentages over the core interval spanning about the past 6500 years implies no regional vegetation change. Known climatic oscillations over that interval, including those associated with Neoglaciation (e.g. Denton and Karlén, 1973) had no detectable impact upon the lowland vegetation insofar as can be detected from pollen data. Rampton (1971a) cites evidence for minor fluctuations of altitudinal treeline in southwestern Yukon Territory in recent centuries. It is likely that similar fluctuations occurred in interior Alaska during the past 6500 years, but they cannot be detected in the lowland pollen records.

HEALY LAKE

Healy Lake (Fig. 17, Fig. 18) is a shallow lake with an estimated average depth of about 1.2 meters and an area of about 13 km^2. The lake is of particular interest because of recent archeological investigations in the area. The Village Site is the oldest of several known archeological sites at Healy Lake and has been occupied intermittantly for more than 10,500 years (Cook, 1969).

In conjunction with the archeological investigations at the lake, Ager (1972) studied the surficial geology and geomorphology of the area in an effort to reconstruct late Quaternary history. It is useful here to summarize the major conclusions of that investigation.

(1) During the Donnelly (Wisconsin) Glaciation, a lake partly occupied the lower Healy Valley. Lake level was perhaps several feet higher than at present. Lake formation was due to rapid deposition of outwash across the lowermost Healy Valley by the Tanana River. During the time of existence of the Wisconsin-age lake, the headwaters of the Healy River in the Yukon-Tanana Upland were glaciated. The Healy Lake area had a windswept periglacial environment with sparse vegetation and extensive deposition of eolian sand and loess. Ice wedges formed on south-facing slopes where no permafrost now exists.

(2) Lake level dropped or the lake drained completely prior to the initial human occupation of the Village Site about 10,500 or 11,000 years ago. Lake drainage was probably due to breaching of the outwash dam by the Tanana River, or less likely, by tectonic subsidence. The former lake site became a floodplain for the Healy River, which no longer drained glaciated headwaters. By mid-Holocene time, the lower Healy River floodplain had developed bog flats underlain by discontinuous permafrost. The bog flats became pitted with thermokarst lakes and ponds and interlaced with forested levees.

(3) The present lake was formed in late Holocene time as a result of renewed aggradation of the Tanana River floodplain, perhaps in response to Neoglacial events in the Alaska Range. No precise date for the time of lake formation was obtained, however. As in the case of other major lakes in the valley, deposition of an outwash dam by the Tanana River across the lower end of the Healy River Valley impounded the lake. The process is continuing today. Nearly every summer when the Tanana River level rises, its silt-laden waters back up into the lake, depositing deltaic sediments in the western half of the lake and temporarily raising the lake level a meter or

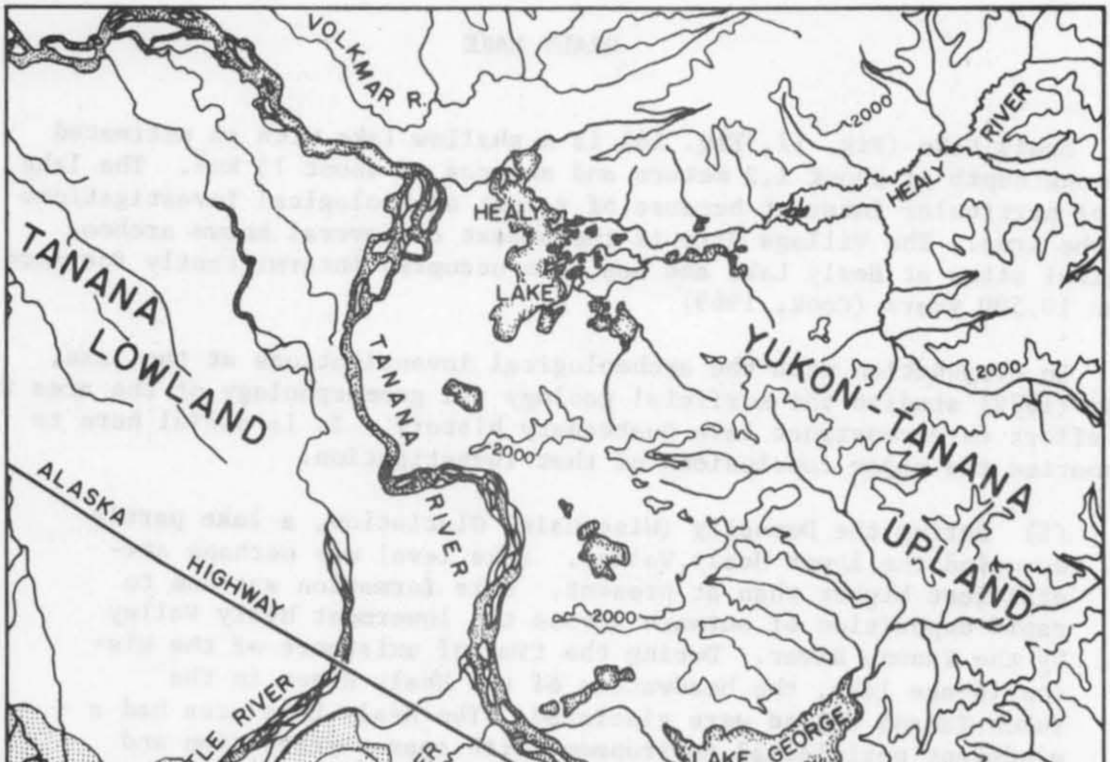

Fig. 17. Map of Healy Lake-Lake George Area. Glacial Geology is based upon Holmes and Foster (1968) and Moffit (1942). Base map compiled from U.S. Geological Survey Mt. Hayes and Big Delta 1: 250,000 Quadrangles.

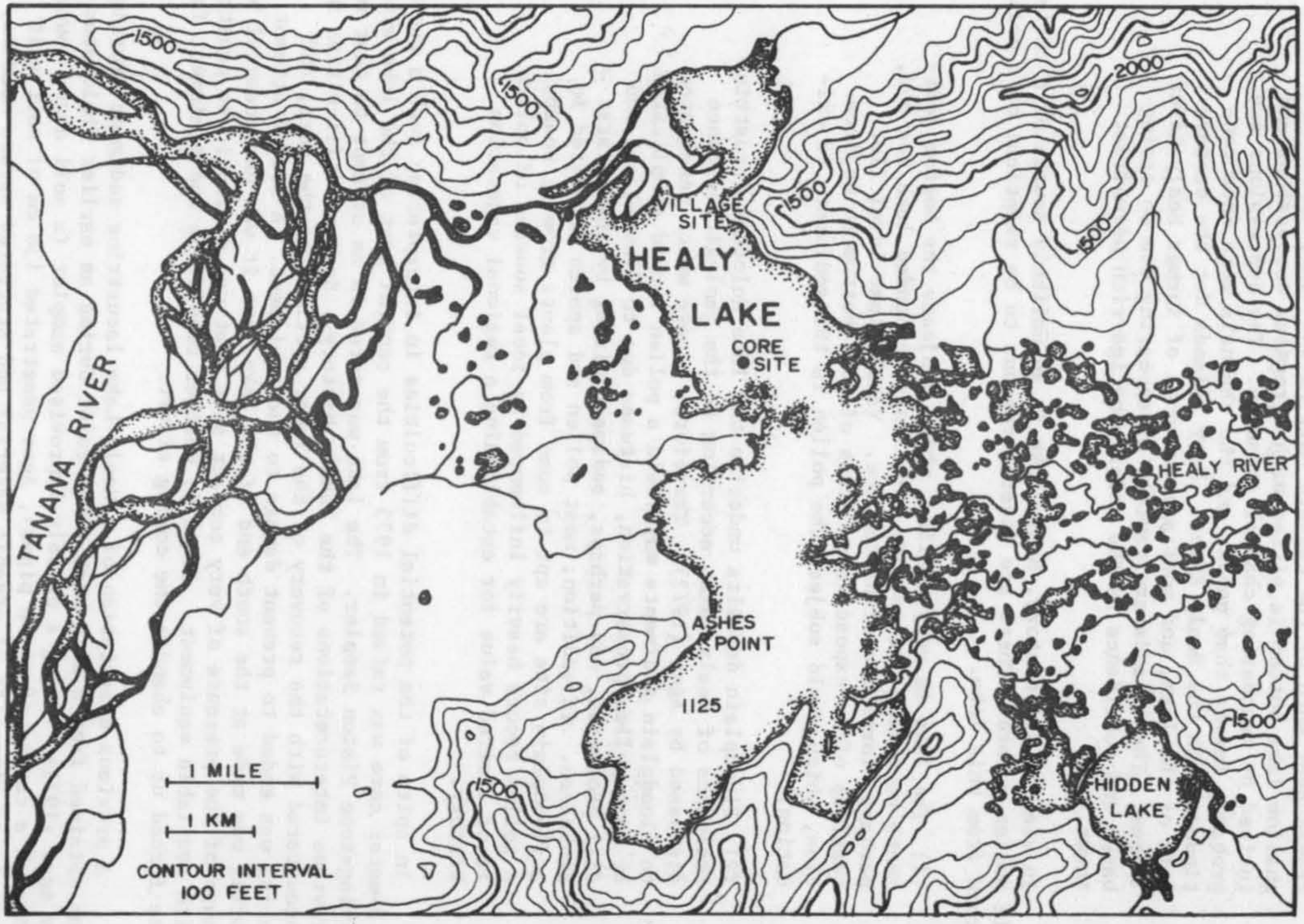

Fig. 18. Map of Healy Lake area.

more. When lake level is low, inundated bog flats can be traced over much of the eastern half of the lake, where the shallow lake bottom is pitted with irregular depressions and incised by meandering channel segments. The depressions are probably former thaw ponds, and the channels were once continuous with the Healy River. Many islands dot the eastern half of the lake, and most are remnants of former Healy River levees. The islands are rapidly disappearing due to caving banks and subsidence as the underlying ice-rich permafrost thaws.

In view of its history, Healy Lake is an unlikely source of a reliable pollen record. There are several reasons to be skeptical of a pollen record from this lake.

(1) The lake is very shallow, which subjects the bottom sediments to mixing due to wave turbulence, grounded lake ice and, perhaps, formation of bottom ice. Yearly lake-level fluctuations often expose large areas of lake bottom to desiccation, which would subject the pollen in the sediments to oxidation.

(2) Floodplain deposits underlie the late Holocene lacustrine sediments of Healy Lake, according to the geologic evidence discussed by Ager (1972). Therefore, a core which penetrates to floodplain sediments may yield a pollen record complicated by poor pollen preservation, hiatuses due to fluvial cut and fill processes, and perhaps, sediment mixing by thermokarst processes. In addition, most pollen and spores deposited in a floodplain site are apt to come from plants growing nearby. A pollen record heavily influenced by local sources of pollen is of limited value for establishing a regional vegetation history.

In spite of the potential difficulties in interpreting such a record, a 3-meter core was raised in 1973 from the central part of the lake with a Livingstone Piston Sampler. The lake was cored in an attempt to test my previous interpretations of the lake's history. Serious difficulties were encountered with the recovery of the lower sections of the core, and coring was ended to prevent damage to the equipment. A second attempt at coring was made at the south end of the lake, but it was unsuccessful because of the presence of very compact silt that was difficult to penetrate with available equipment. Finally, weather conditions and equipment failure forced us to abandon the coring effort.

A previous description of a Healy Lake lacustrine sediment profile was obtained from a site near Ashes Point during an earlier field season by Ager (1972). Using a crudely-improvised sampler (a soil auger lowered through a casing of stove pipes), Ager penetrated 138 cm of soft silt containing fine bits of organic material and scattered spruce needles.

Underlying the silt was well-rounded fluvial gravel as much as 5 cm in diameter (the largest size recoverable with the auger). The pebble types suggest an Alaska Range origin rather than a Healy River basin origin. This interpretation requires that prior to the silt deposition near Ashes Point, a slough of the Tanana River, bearing outwash gravel, meandered into at least the western part of the present lake area. Unfortunately, no pollen data are available from the silt overlying the gravel.

Sediment Stratigraphy

The sediment stratigraphy of the Healy Lake core, supplemented by sediment grain-size analysis of 5 core segments, provides a basis for interpreting the most recent portion of the lake's history (Fig. 19, Fig. 20).

The uppermost meter of sediment in the core was probably deposited in a lacustrine environment, except for a layer of woody detritus. Both silts are relatively high in clay content (Fig. 19). No sedimentary structures were detected. The upper detritus layer contained twigs and forest litter. It yielded a radiocarbon date of 1440 ± 85 years B.P. The 13-cm-thick woody debris layer probably accumulated during an interval when most, or all, of the lake was drained and vegetation became established at the core site.

Because Healy Lake is very shallow, only a small drop in lake level would expose much of the lake bottom. Such a change in lake level could be caused by lateral migration of the Tanana River, thus breaching the alluvial sediment dam which separates the lake from the river. Alternatively, a brief episode of downcutting of the nearby Tanana River floodplain or reduced flow of the Tanana River could also lower the lake level. The present altitude of the lake surface is almost the same as that of the Tanana River where the outlet stream of the lake joins the Tanana. Ager (1972) has described present-day seasonal fluctuations in the level of the Tanana River which cause changes in the level of the Healy Lake surface. The flow direction in the "outlet" channel of Healy Lake reverses during early to mid-summer when the Tanana River level rises and its water and sediment are carried into Healy Lake for periods of several days or weeks. If this sensitive relationship between the levels of Healy Lake and the Tanana River has been the same for the past several thousand years, it may provide the mechanism for the lake drainage about 1400 years B.P.

The Healy Lake core sediments that underlie the upper 95 cm of lacustrine silt are composed of silt and sandy silt. Some of the sediments contain scattered fragments of plant detritus, and a woody plant

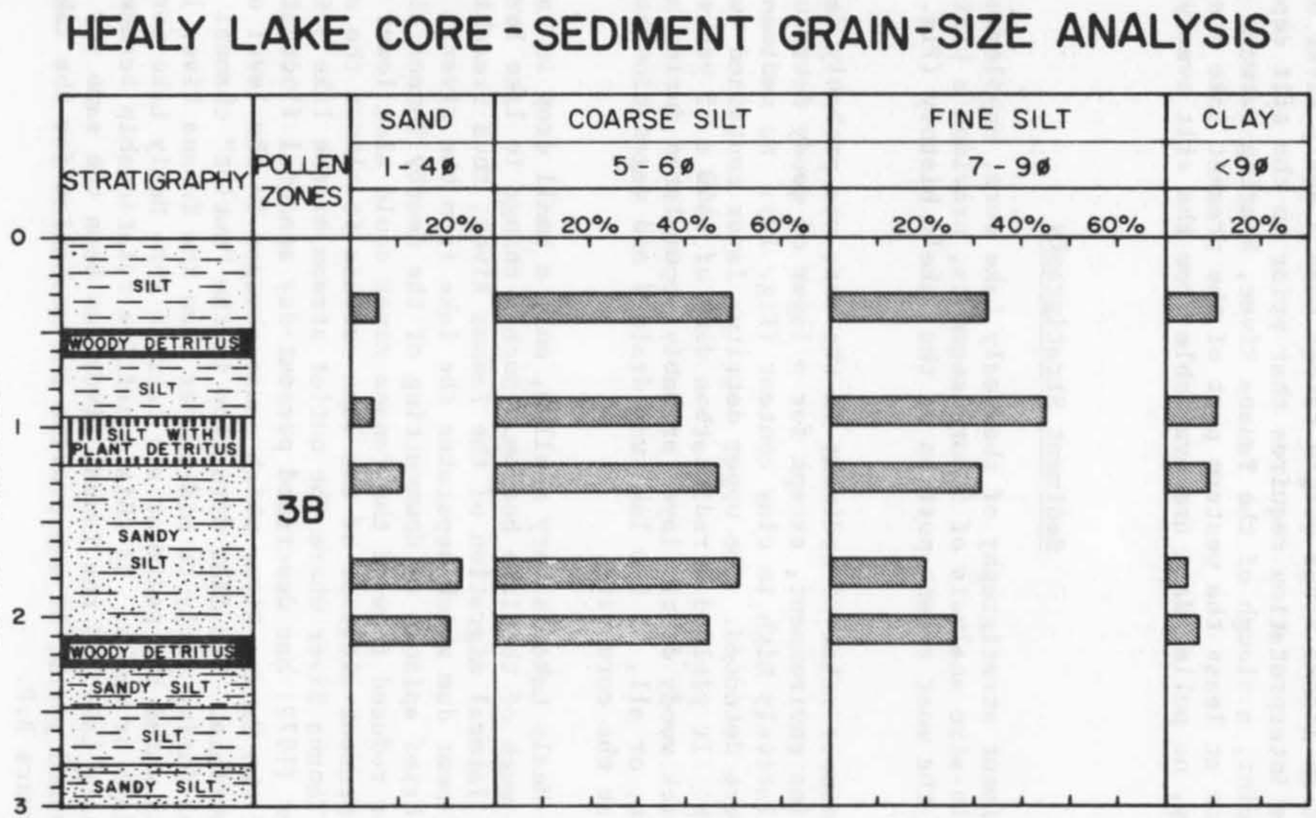

Fig. 19. Sediment Analysis Diagram for Healy Lake Core.

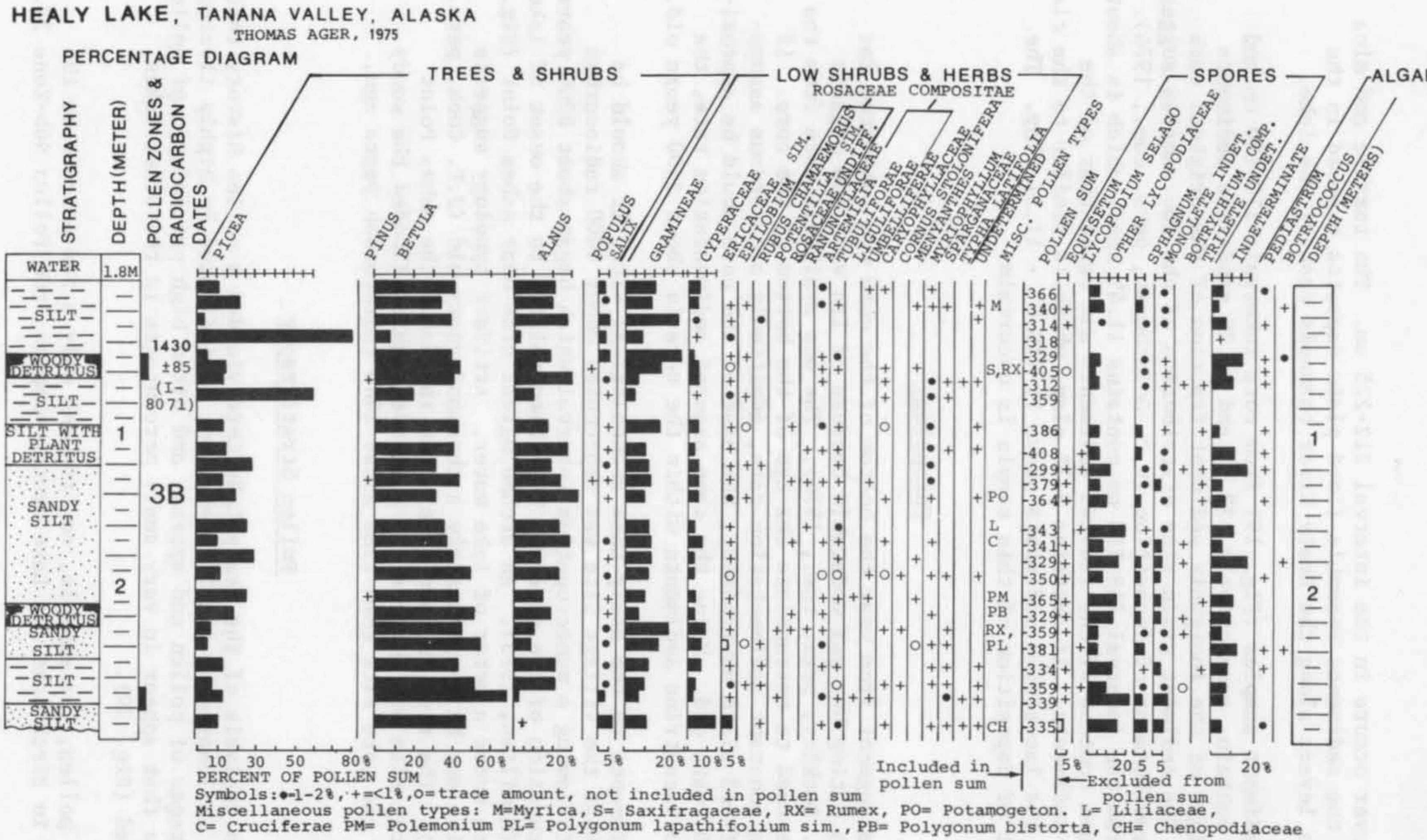

Fig. 20. Pollen percentage diagram, Healy Lake Core.

detritus layer occurs in the interval 212-225 cm. The texture and mica content of the sediments resemble flood plain deposits exposed in the cutbanks in levees along the Healy River channels east of the lake.

Two sediment samples (Fig. 19) from core intervals 170-180 cm and 200-210 cm contain, respectively, 23.9% and 21.2% sand-size sediments (by dry weight of the inorganic sediment fraction of the original core samples). The sediment grain size distribution of the two samples suggests a fluvial environment of deposition (R.P. Goldthwait, pers. com., 1974). A sample from the interval 118-128 cm contains 11.4% sand, which is about half the sand content of the fluvial sediments and twice that of the lacustrine sediments. It contains 9.7% clay, which is similar to the clay content of the lacustrine sediments above it (10.9% - 11.3% clay. The environment of deposition of this sample is uncertain.

Chronology

A core segment from near the bottom of the core was submitted for radiocarbon dating but was undatable because of its very low organic content (J. Buckley, pers. com., 1974). The one available date from the core can be used to extrapolate the age of the bottom of the core. If we assume a constant sedimentation rate, admittedly a hazardous assumption in a flood plain environment, the base of the core would be approximately 7700 years old. Using the same assumed sedimentation rate, the base of the lacustrine sediments within the core is about 2500 years old.

In reference to the Healy Lake archeological site, it should be mentioned that the Village Site was reoccupied about 4000 radiocarbon years ago following a nonoccupation interval which began about 8000 years ago. Reoccupation of the site may have been related to the onset of lake formation (Hamilton, 1973). An archeological site near Ashes Point (Fig. 18) now lies under a meter of lake water. Artifact typology suggests that the site may be approximately a thousand years old (J.P. Cook, pers. com., 1969). The rise in lake level that inundated the Ashes Point archeological site was perhaps the same event which flooded the woody horizon at the core site some time after 1440 radiocarbon years ago.

Pollen Stratigraphy

Pollen analysis of the Healy Lake Core yielded a pollen history that is heavily influenced by local vegetation, as indicated by highly fluctuating percentages of pollen and spores, and often high percentages of pollen from plants that appear in very small percentages in the other lakes investigated (Fig. 20).

Grass pollen, for example, contributes only a few percent to the pollen sum in Birch Lake and Lake George samples from Pollen Sub-Zone 3B.

But several samples from Healy Lake contain in excess of 20% grass pollen. Bog-associated plants such as Ericaceae, Cyperaceae, Lycopodiaceae, Sphagnum, ferns (Monolete spores), and Salix all occur in relatively high percentages in the Healy Lake core. This reflects the proximity and large areal extent of the bog and grassy deltaic mud flats in the Healy Lake area, both at the present time and in the period represented by the sediment core.

In spite of the major influence of local vegetation upon the pollen spectra from Healy Lake, the range of percentages of spruce, birch and alder indicates that the entire core falls within regional Pollen Zone 3B. Alder percentages are very low in the two samples from the bottom of the core. In view of the heavy influence of local vegetation upon the pollen spectra throughout the core, these low alder percentages should be suspect as indications of regional vegetational change. Pollen data and radiocarbon dates from Birch Lake Core II, Johnson River Bog (to be described in the following section), and Matthews' Isabella Basin core near Fairbanks (1974a) show an increase in alder pollen from a few percent or less to significantly higher percentages between 8400 and about 7000 years B.P. In view of the extrapolated date of 7700 years B.P. for the base of the Healy Lake core, it is possible that this alder increase at the base of the Healy Lake core reflects the same region-wide invasion.

Several samples in the upper meter of the core show great fluctuations in percentages of spruce, birch, and alder pollen. These fluctuations are probably the result of pollen deposition in a shallow lake environment where the previously mentioned processes might influence pollen percentages. The two samples with spruce pollen percentages in excess of 58% may reflect near-shoreline conditions which tend to concentrate buoyant spruce pollen, as seen in one of the surface pollen spectra near the shore of Quartz Lake (Locality E, Fig. 8).

but several samples from Healy Lake contain in excess of 20% grass pollen. Bog-associated plants, such as Ericaceae, Cyperaceae, Lycopodiaceae, Sphagnum, Typha (Sparganium type?) and Salix all occur in relatively high percentages in the Healy Lake core. This reflects the proximity and large areal extent of the bog and grassy deltaic mud flats in the Healy Lake area, both at the present time and in the period represented by the sediment core.

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Several samples in the upper meter of the core show great fluctuations in percentages of spruce, birch, and alder pollen. These fluctuations are probably the result of pollen deposition in a shallow lake environment where the previously mentioned processes might influence pollen percentages. Two samples with spruce pollen percentages in excess of 50% may reflect near-shoreline conditions which tend to concentrate buoyant spruce pollen, as seen in one of the surface pollen spectra near the shore of Quartz Lake (Locality 8, Fig. 8).

JOHNSON RIVER BOG

A peat-filled depression near Johnson River was cored with a Hiller Peat Sampler during the 1972 field season (Fig. 21). The peat bog lies adjacent to the Alaska Highway, 0.6 km northwest of the Johnson River Bridge (Figs. 2 and 17). The bog had been cored previously by J.H. Anderson (1974), but in his study only samples from the uppermost 1.5 meters were analyzed for pollen content. Following Anderson's site designation, the bog is herein referred to as Johnson River Bog. The bog overlies glacial drift of Donnelly age (Holmes and Foster, 1968). The depression is perhaps a kettle, but air photo interpretation suggests that it may be part of an abandoned meltwater channel formed during waning stages of the Donnelly Glaciation. The bog differs from other kettle depressions on the Donnelly drift near the Johnson River in that it is almost filled with peat, with only a small patch of open water in the center. In contrast, nearly all other kettles in the area have ponds with only a narrow rim of vegetation.

A 3.1 meter core was raised from the center of the bog, about 1.5 meters from the edge of the small central pond. Further penetration was not possible with the equipment available because a very compact or frozen layer was encountered at 3.2 meters depth. Probes in different parts of the bog struck local impenetrable sediment at shallower depths. Sediment exposures nearby, along the Alaska Highway and the Johnson River, show a thin layer of organic material underlain by about 0.5 m of compact loess. The loess cap overlies Donnelly till. It is likely that the impenetrable layer encountered in the bog was loess, deposited during or immediately following the waning stages of the Donnelly Glaciation.

Sediment Stratigraphy

The stratigraphy and pollen diagram of the Johnson River Bog appear in Figure 22. The upper meter of the core is a fibric sedge peat that grades downward into a detrital peat composed of small fragments of plant material. The detrital peat from the lowermost 10 cm of the core is slightly silty. A radiocarbon assay from the basal 20 cm of the core yielded an age of 7673 ± 193 years B.P. (AU-64). This provides a minimum date for deglaciation of the area, but the date probably postdates ice recession by at least a thousand years. Porter and Carson (1971) cite evidence from Washington to demonstrate a lag of hundreds or even thousands of years between the time of initial ice recession and the deposition of sufficient organic material to obtain radiocarbon dates. Mickelson and Borns (1972) report basal dates from a kettle bog in Maine which suggest a similar lag of about two thousand years. A long lag is also likely in the case of the Johnson River Bog where gradual melting out of stagnant glacier ice and deposition of a blanket of loess is presumed to have preceded accumulation of organic material in the depression.

Fig. 21. Johnson River Bog is a sedge-peat filled depression overlying glacial till of Donnelly (late Wisconsin) age. The bog is surrounded by spruce-hardwood forest.

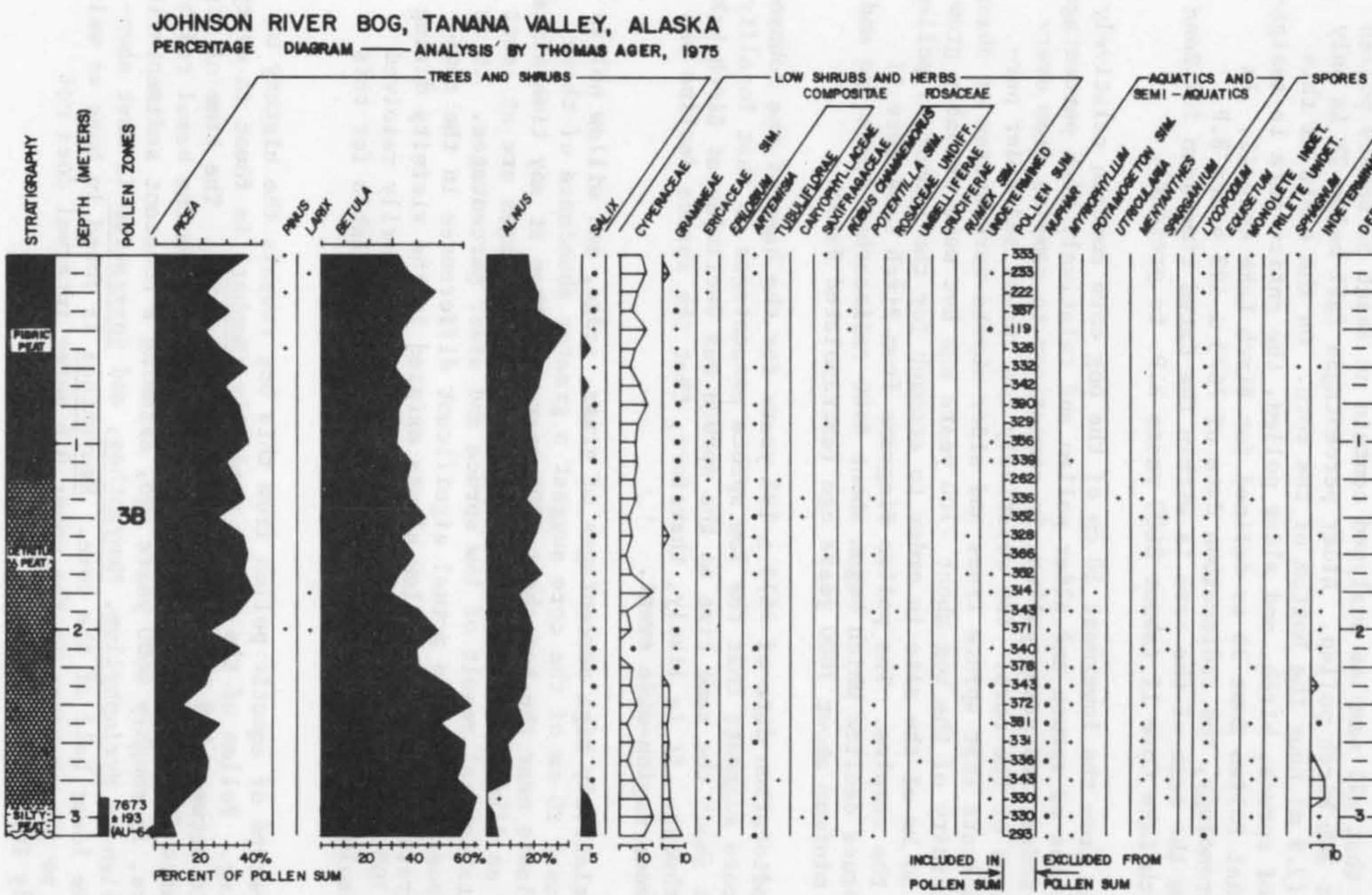

Fig. 22. Pollen percentage diagram, Johnson River Bog.

Pollen Stratigraphy

The pollen percentage diagram for the Johnson River Bog core (Fig. 22) reveals that all samples analyzed contain at least 5% spruce pollen and at least 28% birch pollen. Alder percentages fall below 2% in only one sample (2.9 m) near the bottom of the core. On the basis of this assemblage of spruce, birch, and alder pollen, the entire core is assigned to regional Pollen Zone 3B as defined for Birch Lake Core II. In terms of chronology, the radiocarbon date of 7673 ± 193 years B.P. (AU-64) from the base of the core is within the dated time span for Zone 3B from Birch Lake Core II (about 8400 years B.P. to present).

Samples from the lowermost 20 cm of the bog core contain relatively low percentages of spruce and alder pollen and relatively high percentages of willow, sedge, and grass pollen, in comparison to samples from overlying portions of the core. The relatively low spruce and alder percentages indicate that spruce trees and alder shrubs were sparse or absent from the vicinity of the bog about 7700 years ago but were probably growing within 50 km of the site in order to account for the amount of pollen present in the samples. The pollen diagrams from Birch Lake Core II record a spruce decline which began about 8400 radiocarbon years ago and attained a minimum about 7000 years ago (extrapolated date).

The radiocarbon date of 7673 ± 193 years for the base of the Johnson River Bog core suggests that the low spruce percentages at that locality occurred at about the same time as the spruce was declining at Birch Lake to the northwest. It is likely, therefore, that the spruce decline was a simultaneous region-wide event.

The relatively high percentages of grass, sedge, and willow pollen from the basal 20 cm of the core suggest a greater abundance of these types of plants near the bog about 7700 years ago than at any time since. It is just as likely, however, that the higher percentages are at least partly a statistical result of low spruce and alder percentages. It is therefore possible that no actual significant differences in the abundance of grass, sedge, and willow plants existed in the vicinity during the past 7700 years. This problem cannot be satisfactorily resolved without Absolute Pollen Influx Data, which is not available for this core.

The record of aquatic pollen from this bog reveals the history of pond filling. Pollen of the yellow pond lily (Nuphar) is found in every core sample between 1.8 and 3.1 meters depth (Fig. 21). The time of its disappearance from the pollen record, extrapolated from the basal radiocarbon date, is roughly 4600 years ago, assuming a constant sedimentation rate. Pollen of Myriophyllum, Menyanthes, and Sparganium is most abundant in the lower half of the core. Menyanthes is found in bogs as well as ponds, so its presence in the upper 0.6 meter interval does not necessarily imply open water.

LAKE GEORGE

Lake George (Fig. 23) was formed by the same process of outwash sediment deposition which dammed several lakes on the north side of the Tanana Valley during late Pleistocene time. Of those lakes, however, Lake George was nearest to the Alaska Range and its glaciers (Fig. 17).

Surficial geologic maps of the Lake George-Johnson River area (Holmes, 1965; Holmes and Foster, 1968) show that a glacier from the Johnson River Valley in the Alaska Range advanced to within 5 km of Lake George during the Donnelly Glaciation.

The advance of a Donnelly-age glacier in the nearby Gerstle River area has been dated at 25,300 ± 950 (GX-2179) radiocarbon years B.P. The date was derived from buried twigs that were overridden by the advancing glacier (T.D. Hamilton, pers. com., 1971). Much, if not all, of the Donnelly drift in the Gerstle River area and, presumably also in the Johnson River area, is of late Wisconsin age.

The exact terminal position of the Johnson River Glacier at its maximum is uncertain, but aerial photo interpretation of the Lake George area suggests that the advancing ice may have deflected the Tanana River north of its present location, toward the lake area. The combined massive outwash from the Johnson Glacier and the Tanana River poured into the lower part of the George River Valley, forming a thick dam of coarse gravel that impounded the lake. Shallow weathering profiles in outwash exposed along George Creek near the outlet of Lake George suggest that the outwash was deposited during the Wisconsin Glaciation (R.P. Goldthwait, pers. com., 1973). It is most likely that Lake George was formed during late Wisconsin time.

The present lake has a surface area of 18.4 km^2 and a maximum depth of about 11 m (Swartz, 1966). Coarse outwash gravel covers much of the lake bottom in the southwestern quarter of the lake but grades into fine-grained organic-rich sediments in the deeper parts of the lake.

The bedrock ridges flanking the lake are composed of Birch Creek Schist and Mesozoic-age granite intrusives. As in other localities described in this report, the bedrock is mantled with loess and colluvium. Several small streams enter Lake George, but no data are available on the volume of water and sediment which enters Lake George from them. Observations by Swartz (1966) suggest that the sediment carried in some of the streams is largely organic material.

Ice-push ridges of coarse-grained grus are extensively developed along many portions of the shoreline (Fig. 24). The crests of most of these ridges are 3 to 4 meters above present lake level. It is uncertain whether they were formed during a period of higher lake level or under present conditions. Numerous living trees on the ice push ridges, how-

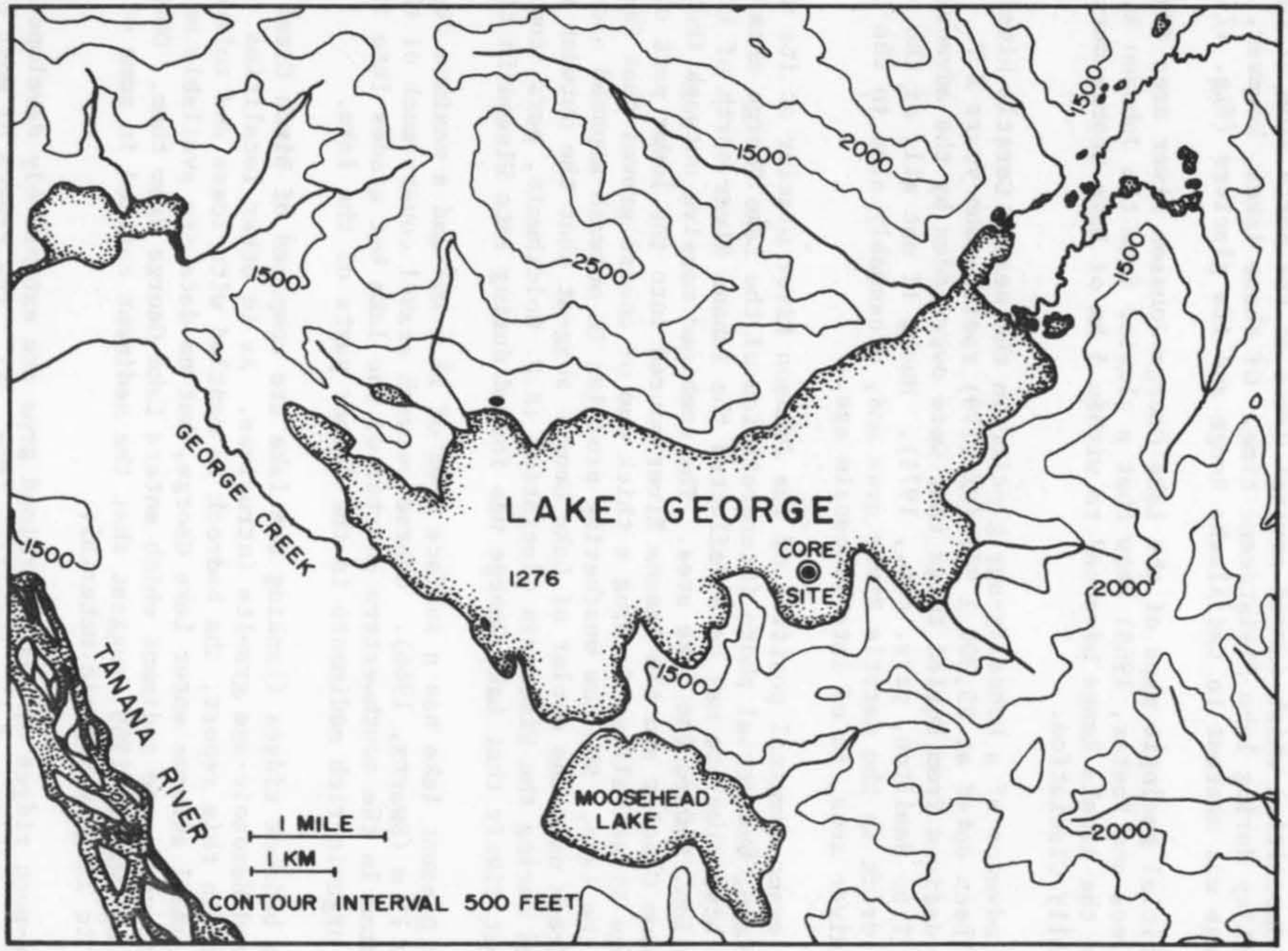

Fig. 23. Map of the Lake George Area, Alaska.

Fig. 24. Ice-push ramparts along shore of Lake George are extensive and well-developed. Crests of the ramparts are generally 3 to 4 meters higher than present lake level. Some tree trunks show evidence of ice abrasion. Photo taken July, 1973.

ever, show damage from lake-ice abrasion. In addition, many tree trunks on the ridges display bends which suggest that the growth of the trees was affected as the ridges were deformed by impinging lake ice. Many recently-formed and older ice-push ridges have been described from Harding Lake in the Tanana Valley (Blackwell, 1965). High ice-push ridges have been observed at Imuruk Lake by Paul Colinvaux (pers. com., 1974), so the high ridges at Lake George are not unique in far northern lakes. It is likely that the size and geometry of the basin of Lake George create conditions that permit these high ridges to form. Ice cover persists on Lake George until early June (Swartz, 1966), which is about a week or two later than on other lakes cored. Ice-shove features can form by ice expansion during warm up periods late in winter and by drifting ice pans striking the shore during spring break-up.

The coring locality from Lake George appears in Figure 23. Lake sediments are less compact in Lake George than at the other localities where coring was conducted. Two cores were obtained from within about five meters of one another in water 10 meters deep. Core II is 8.8 meters long and is presently being used to obtain a paleomagnetic record. Core I is 8.2 meters long and was used for sediment grain-size analysis, pollen analysis, and radiocarbon dating. Radiocarbon dates from the core pose serious difficulties in interpretation, a problem which will be discussed below.

Radiocarbon Dates

Five samples from Lake George Core I were submitted to Teledyne Isotopes for radiocarbon assay. The reported dates appear in Table 3. When arranged in stratigraphic order, the dates are inconsistent in chronological sequence. There are several possible hypotheses to explain such a sequence.

(1) Sediments from hard water lakes often yield spuriously old radiocarbon dates due to the presence of "dead" carbon derived from weathering of carbonate rocks (Ogden, 1967; Shotten, 1972). Lake George is described as a slightly hard water lake by Swartz (1966). Because possible hard water effects were anticipated, $^{13}C/^{12}C$ ratios were run on four of the five samples from Lake George Core I as a means of evaluating the hard water influence upon the dates (Pearson, 1965). The normalized dates resulting from this procedure (Table 3) show that the hard water effect was minimal.

(2) Reworked older sediments could be deposited on top of younger sediments in a lake by slumping and associated turbidity currents. No stratigraphic features or sedimentary structures in the core were observed which would suggest such disturbance, however. The slope of the lake bottom near the coring site is gentle, according to a morphometric map

TABLE 3

RADIOCARBON DATES: LAKE GEORGE CORES

Core I

Sample number	Core interval	Age in radiocarbon years*	C^{13}/C^{12} Normalized age
I-8069	85-99 cm	3170 ± 145 B.P.	no data
I-8204	185-197 cm	1730 ± 185 B.P.	1650
I-8205	285-299 cm	2855 ± 255 B.P.	2770
I-8206	510-525 cm	8410 ± 140 B.P.	8295
I-8207	685-705 cm	7140 ± 160 B.P.	7045

Core II

Sample number	Core interval	Age in radiocarbon years*	C^{13}/C^{12} Normalized age
DIC-315	510-537 cm	$11,520 \pm {}^{130}_{140}$ B.P.	no data
DIC-316	671-694 cm	$12,030 \pm {}^{170}_{180}$ B.P.	no data

* 5568 year half life

by Swartz (1966). It would, therefore, be an unlikely site for slumping to occur. Slumping of lake sediments or a sudden influx of large volumes of reworked colluvium into the lake would probably be registered in the pollen record as mixed pollen assemblages from different pollen zones or as reversed or repetitive stratigraphic order of pollen zones. The pollen record from Lake George Core I shows no such evidence, however, and the record is very similar to that from Birch Lake Core II.

(3) Burrowing invertebrates such as Tubifex and Tendipes are present in the bottom sediments of Lake George (Swartz, 1966). Because these organisms burrow only to depths of about 10 cm (R.B. Davis, 1967, 1974), mixing of sediments from such close stratigraphic intervals would have only slight effect on radiocarbon dates.

(4) Spurious dates in the lower part of a core from St. Paul in the Pribilof Islands (Colinvaux, 1967b) were explained by groundwater contamination. Groundwater which contained modern carbon percolated through permeable layers of sand in the sediments underlying the lake. The modern carbon evidently contaminated core samples from intervals adjacent to the sand layers (Colinvaux, pers. com., 1974). No sand or gravel layers were encountered in Lake George cores. The sediments are composed of mostly silt and clay-size particles which would not be very permeable. It is therefore unlikely that groundwater contamination provides an explanation for the inconsistencies in the sequence of radiocarbon dates from Lake George Core I.

(5) Contamination of samples during coring, storage, subsampling and processing would result in spurious dates. Great care was taken at all stages of the field and laboratory work to insure that no such contamination occurred, however, and the procedures followed are described in the Methodology section.

I see no obvious explanation to account for the internal inconsistencies in the sequence of dates from Lake George. The uppermost radiocarbon date from the core is probably reliable, however, because there is a means of testing it. There is a 3 mm-thick layer of fine-textured white volcanic ash at a depth of 48 cm below the top of the core. The ash is composed of silt-sized glass shards. The ash horizon shows up distinctly on x-radiographs from Lake George Cores I and II. It is likely that the ash layer is the White River Ash, which is a widespread marker horizon in eastern Alaska and southern Yukon Territory. Its distribution and composition have been studied by Lerbekmo and Campbell (1969). The probable source of the ash is a volcanic vent near Mt. Natazhat in the St. Elias Range near the Alaska-Yukon border. The ash has been differentiated into two lobes, each of which evidently represents different eruptions. The western lobe of the White River ash has been bracketed by radiocarbon dates of 1520 ± 100 and 1750 ± 110 B.P. (Fernald, 1962). An earlier estimate of the age of the ash is 1400 years B.P. based upon calculated accumulation rates of peat (Capps, 1916). More recently, Hughes et al. (1972) report dates that suggest the ash may be 1850-1900 radiocarbon years old.

If we assume the age of the ash is midway between Fernald's (1962) bracketing dates, we can calculate the average sedimentation rate for the uppermost 48 cm of the core. This yields a rate of about 34 years per cm. If that sedimentation rate is then used to calculate the age of the core at a depth of 92 cm, it yields an age of about 3128 years. The radiocarbon date from core interval 85-99 cm is 3170 ± 145 years B.P. (Table 3). If the 1400 year date is used for the age of the ash, the calculated age of the core at 92 cm is 2683 years B.P., which still agrees rather reasonably with the radiocarbon date. Similarly, the 1900 year date for the ash suggests the age of the core at 92 cm is 3640 years B.P. Thus it appears that the uppermost date in the core is acceptable, but the remaining dates should be considered spurious.

A second core (Lake George Core II) was raised from within 10 m of the Lake George Core I site. Difference in water depth between the two sites was about 15 cm. Two samples from Lake George Core II were submitted to Dicar Radioisotopes Laboratory for dating (Table 3). The resulting dates of $11,520 \pm {}^{130}_{140}$ and $12,030 \pm {}^{170}_{180}$ B.P. are considerably older than the dates from the lower portion of Lake George Core I (Table 1). Stratigraphic correlations between the cores are as yet uncertain, however, particularly in the lower 3 meters of the the cores. Inspection of the sediments and x-radiographs suggest that the upper 5.5 meters of the cores are very similar in color, texture, and sedimentary features. The upper ash layer and section of laminated marl, for example, occur at about the same stratigraphic intervals in the cores. The pollen and sediment from Lake George Core II have not yet been analyzed, however.

Lake George Core I Sediment Stratigraphy

The upper 4.6 meters of Lake George Core I sediments are composed of soft organic-rich silt, black (5Y 2/1) when moist and freshly extruded. Organic content in this interval is 5.4 - 9.3% of dry sample weight (Fig. 25). Most of the sediments in this interval are homogeneous and structureless. Some diffuse layering is detectable, however, and seems to reflect slight variations in sediment texture.

The interval 4.5 - 5.3 meters in the Lake George Core is partly laminated black silt that contains abundant fragments of soft plant tissues. The boundaries between the laminae are formed by thin layers of pale yellow calcium carbonate (5Y 7/3) and thin films of organic detritus.

At a depth of 5.3 meters, the laminae become more sharply defined and grade into a 60 cm thickness of thinly-laminated marl. The fine

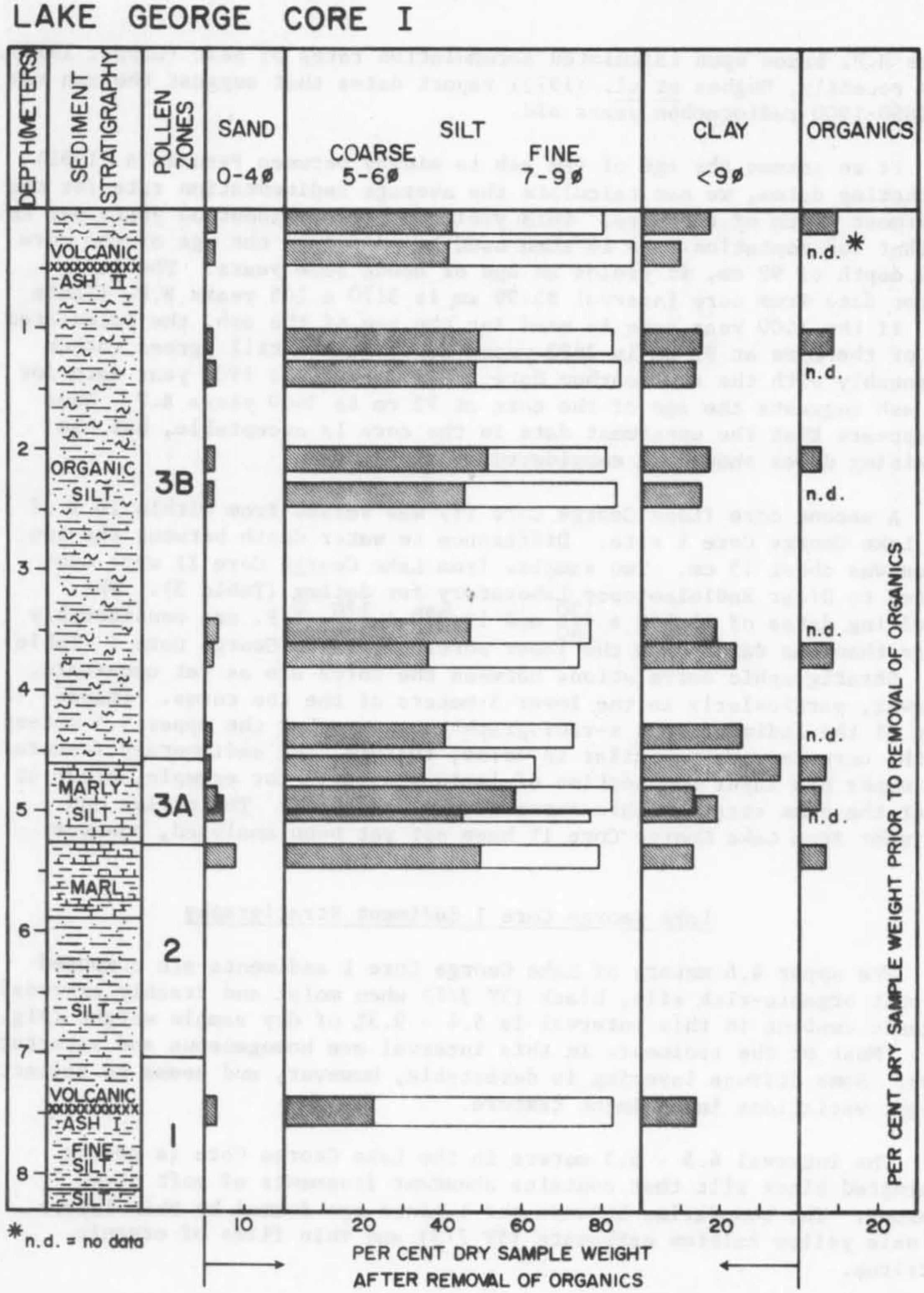

Fig. 25. Sediment Analysis Diagram for Lake George Core I.

laminations suggest a deepwater environment of deposition. R.B. Davis (1974) has shown that lake bottom burrowing invertebrates tend to disrupt or destroy laminations in soft sediments. The absence of disruption of the laminae in this segment of the core implies that such burrowing organisms were absent from at least part of the lake during the deposition of this interval. The laminae are difficult to count accurately because many seem to be discontinuous, but the laminated section of the core between 5.3 and 5.8 meters contains a minimum of 665 laminae. If the laminae are annual depositional features, then the approximate sedimentation rate over that core interval was 13.3 years/cm (0.077 cm/yr).

The underlying section of the core consists of rather structureless silt, which is black (2.5Y 2/0) to very dark gray (5Y 3/1) in color when moist, and is slightly micaceous. The texture becomes finer between 7.7-8.1 m, and the moist color changes to dark gray (2.5Y 3/0 to 2.5Y 2/0). The fine silt and clay fraction of the core sediments in the 7.7-8.1 m interval contains little organic material. These sediments were perhaps derived from glacial outwash sediments entering the lake from the Tanana and Johnson Rivers during late Wisconsin time. A sediment sample from this core section was used for grain-size analysis and shows a high percentage of fine silt (61.2%). The sand fraction obtained from the sample is volcanic ash of andesitic composition. Some of the ash fragments are sharp black glass shards which do not appear to have been transported by fluvial processes. The source of the volcanic ash is unknown.

Pollen Stratigraphy

Lake George pollen stratigraphy matches that of Birch Lake Core II rather closely, although there are some differences (Figs. 14 and 26). The same zones occur in the two cores in the same stratigraphic order. The Lake George core shows no effects of unusual local events such as those which occur in Zone 1 of Birch Lake Core II, when lake level evidently rose significantly. There is no detected evidence of reworked pollen and spores in the Lake George Core. There are some subtle differences between the cores, however, that require discussion.

Zone 1 pollen spectra from Lake George contain often substantially greater amounts of pollen of various opportunistic herbs such as Plantago, Tubuliflorae, Liguliflorae (probably Taraxacum), Caryophyllaceae, Chenopodiaceae, Thalictrum, and Cruciferae than occur in Birch Lake Zone 1 samples. Whether or not this is a result of differences in local vegetation or of pollen preservation is unknown. The minor assemblage of opportunistic herbs seen in Lake George Zone 1 samples bears a strong resemblance to the minor elements of the late Wisconsin-age pollen spectra from Cape Deceit on Seward Peninsula (Matthews, 1974b).

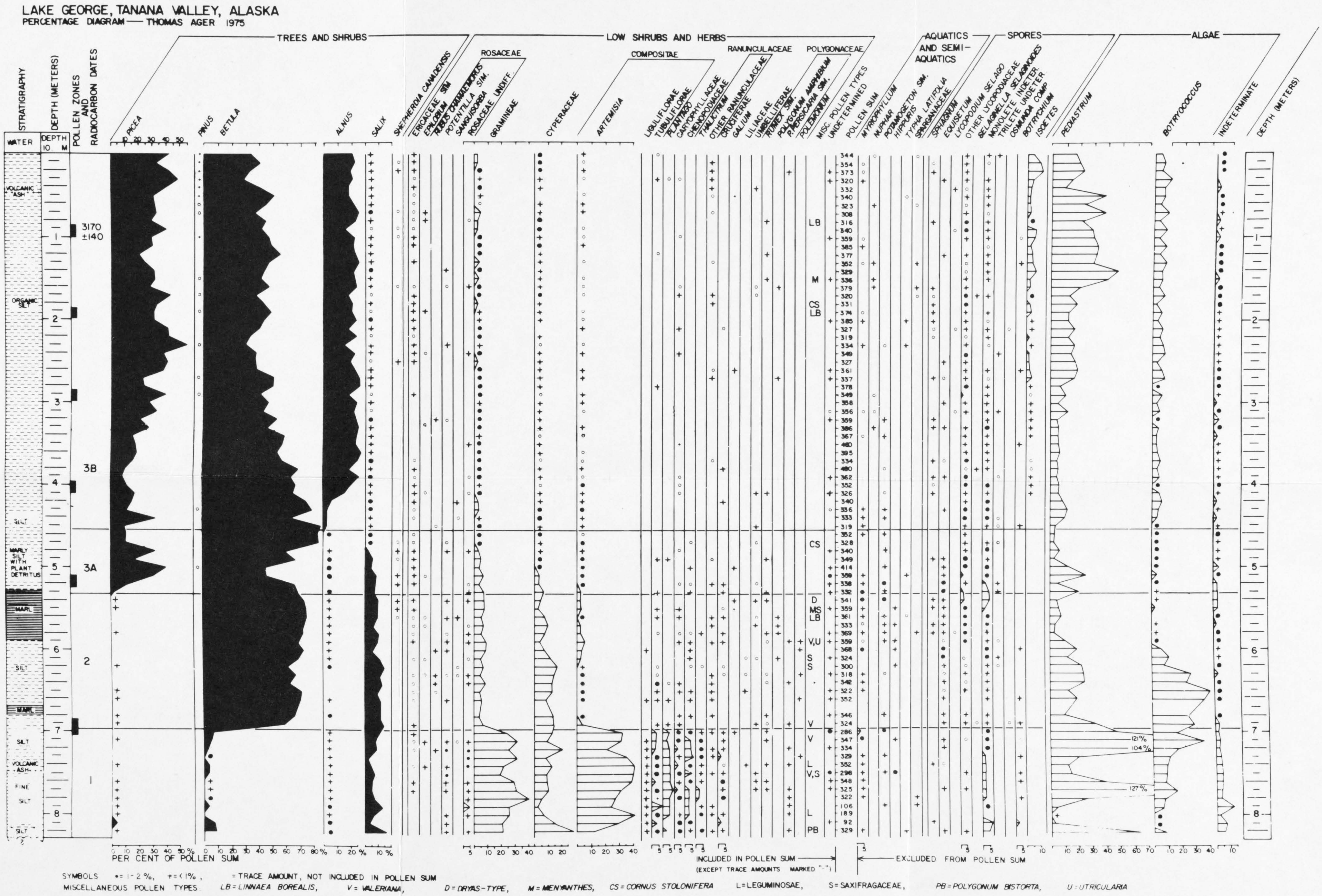

Fig. 26. Pollen percentage diagram, Lake George Core I.

Pollen Zone 2 spectra from Lake George closely resemble those from Birch Lake. Shrub tundra near the two sites was evidently quite similar. In both the above cores, *Artemisia* is present but in much smaller percentages than in Zone 1 spectra. Perhaps *Artemisia* persisted in areas of disturbance such as outwash and loess plains near the Tanana River during the time when Zone 2 pollen was deposited.

Pollen Subzone 3A differs from that in Birch Lake Core II in that it displays a steeper initial increase in spruce percentages. Perhaps Lake George was nearer to the site of initial spruce invasion into the middle Tanana Valley than Birch Lake was. Spruce percentages begin to decline below the upper boundary of Subzone 3A in Lake George whereas they begin to decline *at* the boundary in Birch Lake Cores I and II. Subzone 3B from both Lake George and Birch Lake shows an interval of low spruce percentages (often less than 15%) in the lower part of the zone. This is followed by a rise of spruce pollen percentages, which remain between 20-40% of the pollen sum.

The pollen record from Lake George Subzone 3B bears a striking resemblance to the pollen record from Johnson River bog (Fig. 21) which is assigned in its entirety to Pollen Subzone 3B. Alder percentages at the base of the Johnson River Bog profile and the bottom of Lake George Subzone 3B both display a gradual rise. The general trends of spruce and birch pollen percentages are also quite similar. This similarity is perhaps not surprising in view of the fact that the 2 sites are only a few km apart. The similarity in pollen profiles simplifies the problem of correlation on the basis of pollen stratigraphy (Fig. 27).

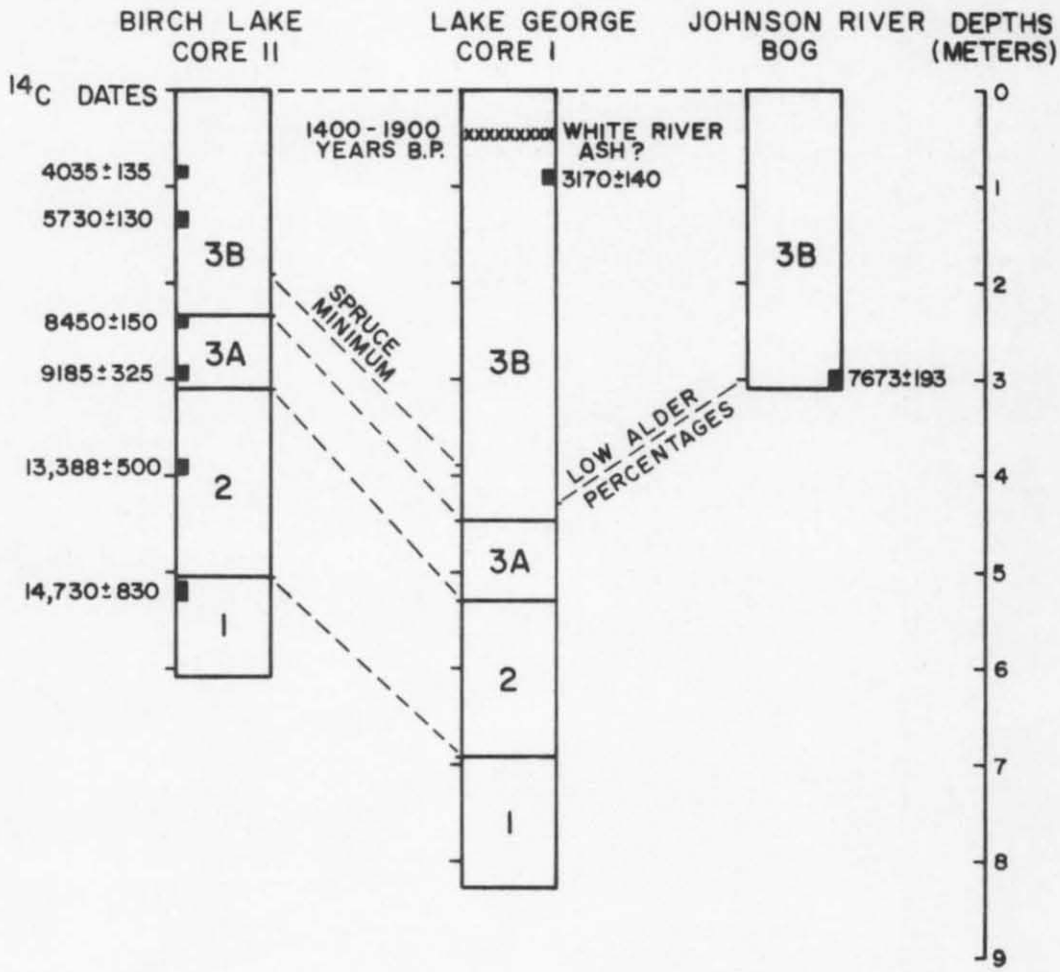

Fig. 27. Pollen-stratigraphic correlation of three lacustrine cores from the Middle Tanana Valley, Alaska.

PALEOENVIRONMENTAL IMPLICATIONS FOR EARLY MAN IN INTERIOR ALASKA

This investigation contributes to the paleoenvironmental framework established by previous workers (e.g. Matthews, 1974a; Guthrie, 1968a; 1968b; Repenning et al., 1964; Péwé, 1965; 1966) for the late Quaternary of interior Alaska. Such a framework is essential to understanding the human ecology of Early Man in Alaska. In recent years several archeological sites older than 9500 years have been discovered in Alaska (Anderson, 1968; Cook, 1969; Dixon, 1969; Dixon, 1973; Hamilton, 1974). Two of the known Early Man sites are located within the Tanana River drainage basin. These are the Village Site at Healy Lake (Cook, 1969; Figs. 18 and 19), and the Dry Creek Site, located in the northern foothills of the Alaska Range near the town of Healy, north of Mount McKinley National Park.

Radiocarbon dates associated with artifacts, hearths, and burned bone indicate that the Village Site at Healy Lake was occupied intermittantly from about 8200 to 10,500 or 11,000 years ago, and also during the past 4000 years (Cook, 1969, Ager, 1972).

Only preliminary archeological research has been done at the Dry Creek Site, but initial radiocarbon dates and stratigraphic studies suggest human occupation at least as early as 10,690 ± 250 years ago (T. Hamilton, 1974 and pers. com., 1975).

Pollen evidence from the middle Tanana Valley suggests that the local vegetation in the Healy Lake area at the time of earliest human occupation was probably shrub tundra. The Dry Creek Site was occupied at about the same time, but its setting in the Alaska Range foothills makes it hazardous to assume a similar local vegetation. Glaciers were probably still extensive but waning in the Alaska Range 11,000 years ago. It is likely that the environment near Dry Creek at that time of occupation was windswept and rather barren. The well-drained outwash and eolian deposits in the area were probably sparsely vegetated by pioneer type plants such as grasses and herbs, but this is not yet established by pollen or macrofossil evidence.

The present study provides a sufficiently detailed vegetational history of the Tanana Lowland to justify speculating about the possible interrelationships between vegetation change, Early Man, and the late Pleistocene large-mammals in interior Alaska. This investigation suggests that a major climatic and vegetational change occurred in interior Alaska about 14,000 years ago. It is very likely that such a dramatic and rapid shift from steppe-tundra to shrub tundra vegetation would have had considerable negative impact upon the herds of large grazing mammals which roamed the region (Guthrie, 1968a). Habitats providing suitable forage for the grazers were probably largely eliminated, except perhaps on or near active glacial outwash plains and on steep south-facing slopes of the Yukon-Tanana Upland.

That such local habitats did persist after the regional vegetation change 14,000 years ago is supported by pollen and macrofossil evidence from Isabella Basin near Fairbanks (Matthews, 1974a). His evidence suggests that grasses and Artemisia were abundant near that Upland locality at a time when dwarf birch was widespread in the region in latest Wisconsin time.

Perhaps the remnant populations of the large grazing mammals survived in such localized marginal habitats for several thousand years after the major shift from steppe-tundra to shrub tundra. The area near Dry Creek may have provided such a marginal habitat for grazers. If so, that offers a likely explanation for man's presence in mountain valleys where the environment was still quite severe nearly 11,000 years ago. Bone fragments identified as remains of extinct bison and horse were found at the Dry Creek Site in association with the evidence of human occupation (R.D. Guthrie, pers. com., 1974). The harsh periglacial setting of Dry Creek is not unique for Early Man sites in Alaska. The Gallagher Flint Station is an Early Man site in the Brooks Range of northern Alaska. It too is located in a glaciated mountain valley and was occupied by man about 10,500 years ago soon after ice had retreated from the site (Dixon, 1973).

Both the Dry Creek and Gallagher sites were probably seasonal hunting camps occupied about 10,500 years ago when the last large grazing mammals such as bison and horses may have been concentrated in such rigorous habitats. If hunting pressure was heavy, man may have contributed significantly to the ultimate extinction of the declining populations of grazing mammals. Man's impact upon the grazers may have been less critical however, than the ultimate loss of even those remaining marginal habitats at the end of Wisconsin time, when further climatic change to warmer conditions permitted the rapid spread of forest vegetation over much of the region in early Holocene time.

SUMMARY OF ENVIRONMENTAL HISTORY

The oldest pollen records obtained during this investigation begin about 16,000 years ago during the late Wisconsin Glaciation. At that time the Alaska Range was more extensively glaciated than at present. The Tanana Valley was unglaciated, however, except in a few localities where Alaska Range glaciers advanced into lowland areas. The environment of the unglaciated interior of Alaska was severely periglacial during late Wisconsin time. Permafrost was probably continuous, whereas today it is discontinuous. Large ice wedges formed where no permafrost occurs today. Strong winds from the south and southwest swept across vast barren outwash sediments of the lowlands and carried sand and silt to the hills of the Yukon-Tanana Upland. Rapid deposition of glaciofluvial sediments rapidly aggraded the Tanana River floodplain. One result of this rapid aggradation was the damming of small south-flowing tributaries from the Yukon-Tanana Upland. Birch Lake, Lake George, Quartz Lake, and perhaps several other lakes were formed in this manner during the late Pleistocene. Data from this study suggest that at least Birch Lake, and probably Lake George were formed during the late Wisconsin Glaciation.

Pollen data from lacustrine cores from Birch Lake and Lake George suggest that prior to about 14,000 years ago, during late Wisconsin time, the vegetation of the middle Tanana Valley and perhaps much of interior Alaska was steppe-tundra characterized by grasses, Artemisia, some sedges, and a number of opportunistic herbs such as Plantago, Taraxacum, and various Compositae and Cruciferae. Climate during that full-glacial interval was extremely continental, with very severe winters and dry, warm summers of short duration. Mean annual temperature was perhaps in the range of $-7^{\circ}C$ to $-12^{\circ}C$, whereas at present it is about $-4^{\circ}C$ in the lowland. Pollen of spruce and alder are nearly absent in sediments of late Wisconsin age from the region. This suggests that trees were eliminated in interior Alaska at that time, probably as a result of aridity and short growing season rather than inadequate summer temperatures.

A sudden climatic change to moister, warmer conditions occurred roughly 14,000 years ago. The degree of climatic change is unknown, but it was sufficient to permit an abrupt vegetation change from steppe-tundra (Pollen Zone 1) to shrub tundra (Pollen Zone 2). Shrub tundra of Zone 2 time was composed of shrub birch, willows, sedges, grasses, and heaths. Shrub tundra persisted until about 10,000 years ago, when trees began to invade the region, probably along rivers initially. The date of initial appearance of trees is uncertain but it could be as early as 11,000 years B.P. Pollen Subzone 3A records the spruce invasion. Spruce-paper birch forests replaced most of the shrub tundra by about 9000 years B.P. The spruce invasion may reflect a further warming of climate, but the range of dates is too broad to justify close correspondence between the time of climate change and the spruce invasion. If spruce were indeed eliminated from interior Alaska during late Wisconsin time, a considerable lag would be expected between the time of suitable climatic conditions and the time when spruce arrived in the region from a distant refugium.

Pollen Subzone 3B spans the past 8400 years. The base of the pollen zone is marked by the appearance of alder pollen, which increased abruptly and has been an important component of the regional vegetation for the past eight millenia. A decrease in spruce pollen percentages and Absolute Pollen Influx began early in Subzone 3B time and continued to decrease until about 7000 years B.P. The decrease suggests a significant regional decline in the spruce forests. The cause of the spruce decline is unknown, but it is possible to speculate that climate had at least an indirect influence. An interval of warm, dry conditions would tend to favor increased frequency of forest fires, which would in turn maintain forests in early successional stages, and thereby favor paper birch and aspen over spruce. Disease is also a factor which could explain the spruce decline, however.

The pollen record suggests that in terms of composition and relative proportions of major plant taxa represented, the vegetation of the Tanana Lowland and adjacent upland areas has remained remarkably stable for the past 6500 years. The climatic changes that are known to have occurred during that interval, including those associated with Neoglaciation, had no discernable effect upon the lowland vegetation of the Tanana Valley. Altitudinal tree line probably fluctuated during the past six millenia, but such relatively minor fluctuations had no discernable effect upon lowland pollen rain.

APPENDIX A

VASCULAR FLORA OF CORING LOCALITIES

IN TANANA VALLEY

The following table provides a list of vascular plants that were collected or observed in the vicinity of coring localities in the Tanana Valley. Because the amount of time devoted to botanical research was rather limited, these lists are incomplete. Concentrated botanical investigation will, without doubt, greatly lengthen the list. Thus, the absence of a given taxon at any of the listed sites is not to be assumed simply because it does not appear in the table for that site.

The species listed from Lake George have been supplemented by published vegetation data for that locality (Swartz, 1966). A much greater number of species was collected from the Delta Junction-Donnelly Dome area by William S. Benninghoff in conjunction with a terrain analysis study of the U.S. Army testing area at Fort Greely (Holmes and Benninghoff, 1957). Since parts of that area include tundra vegetation, Benninghoff's list includes many species which are unlikely to now occur in the vicinity of the coring localities. Tundra is interpreted to have extended to the coring sites during late Wisconsin time, however, so it is useful to refer to Benninghoff's species lists, as well as range maps in Hultén (1968). Quartz Lake is included in the table because the lake was cored, and plants were collected there during 1973; but the analysis of Quartz Lake cores has not yet been undertaken.

APPENDIX A

TAXON	BIRCH LAKE	QUARTZ LAKE	HEALY LAKE	LAKE GEORGE
ALISMACEAE				
Sagittaria cuneata				x
ARACEAE				
Calla palustris	x		x	x
ASPIDIACEAE				
Gymnocarpium dryopteris			x	
ATHYRIACEAE				
Cystopteris fragilis			x	x
BETULACEAE				
Alnus crispa	x	x	x	x
A. incana subsp. tenuifolia	x	x	x	x
Betula nana subsp. exilis	x	x	x	x
B. glandulosa	x	x		
B. papyrifera subsp. humilis	x	x	x	x
BORAGINACEAE				
Mertensia paniculata	x	x	x	x
CALLITRICHACEAE				
Callitriche hermaphroditica				x
CAPRIFOLIACEAE				
Linnaea borealis	x	x	x	x
Viburnum edule	x	x	x	x
CARYOPHYLLACEAE				
Moehringia lateriflora	x	x	x	x
Silene menziesii subsp. williamsii			x	x
S. repens		x	x	x
Stellaria calycantha				x
S. crassifolia				x
S. longifolia				x
S. edwardsii ?	x	x		x

	BIRCH LAKE	QUARTZ LAKE	HEALY LAKE	LAKE GEORGE
CHENOPODIACEAE				
Chenopodium rubrum			x	
COMPOSITAE				
Achillea borealis		x	x	x
Antennaria rosea			x	
Arnica frigida				x
Artemisia arctica subsp. arctica		x	x	x
A. frigida				x
A. telesii				x
Aster sibiricus		x	x	x
Erigeron acris subsp. politus		x		
E. glabellus subsp. pubescens		x		
Matricaria matricarioides	x		x	
Petasites frigidus		x	x	x
P. sagittatus		x		
Saussurea angustifolia		x		
Senecio congestus		x		x
Solidago decumbens		x		x
S. canadensis		x		
Taraxacum sp.	x			
CORNACEAE				
Cornus canadensis	x	x	x	x
CRUCIFERAE				
Arabis lyrata subsp. kamchatica				x
A. hirsuta subsp. pycnocarpa	x			x
Barbarea orthoceras				x
Capsella bursa-pastoris		x		
Cardamine pratensis subsp. angustifolia	x	x		
Erysimum cheiranthoides subsp. altum			x	x
Rorippa hispida				x
Subularia aquatica				x
CYPERACEAE				
Carex canescens	x			
C. crawfordii				x
C. disperma		x		
C. media		x		
C. rostrata		x		
C. vaginata		x		
Carex spp. (other)	x	x	x	x

	BIRCH LAKE	QUARTZ LAKE	HEALY LAKE	LAKE GEORGE
CYPERACEAE				
Eleocharis acicularis				x
E. palustris		x		x
E. quinqueflora		x		
Eriophorum vaginatum		x	x	x
Scirpus validus		x		
ELAEAGNACEAE				
Shepherdia canadensis	x	x	x	x
EMPETRACEAE				
Empetrum nigrum subsp. hermaphroditum	x			
EQUISETACEAE				
Equisetum arvense	x	x		x
E. fluviatile	x	x	x	x
E. pratense	x	x	x	x
E. scirpoides	x		x	x
E. sylvaticum	x	x	x	x
E. variegatum subsp. variegatum	x			
ERICACEAE				
Arctostaphylos uva-ursi		x	x	x
Chamaedaphne calyculata		x	x	x
Ledum palustre subsp. decumbens	x	x	x	x
subsp. groenlandicum				x
Oxycoccus microcarpus			x	
Vaccinium uliginosum subsp. alpinum		x	x	x
V. vitus-idaea subsp. minus	x	x	x	x
FUMARIACEAE				
Corydalis sempervirens				x
GENTIANACEAE				
Menyanthes trifoliata	x			
GRAMINEAE				
Agropyron boreale subsp. hyperarcticum				x
A. pauciflorum subsp. pauciflorum		x		
Alopecurus aequalis				x
Beckmannia erucaeformis subsp. baicalensis		x		
Bromus pumpellianus				x
Calamagrostis canadensis		x		x
C. purpurascens	x	x		
Elymus innovatus	x	x	x	x

	BIRCH LAKE	QUARTZ LAKE	HEALY LAKE	LAKE GEORGE
GRAMINEAE				
Festuca altaica				x
F. brachyphylla				x
Glyceria maxima subsp. *grandis*		x		
Hordeum jubatum	x		x	x
Poa glauca		x		x
Puccinellia hauptiana				x
Trisetum spicatum				x
HALORAGACEAE				
Hippuris vulgaris		x	x	x
Myriophyllum spicatum		x		x
HYDROPHYLLACEAE				
Phacelia mollis				x
IRIDACEAE				
Iris setosa subsp. *interior*	x	x	x	x
ISOËTACEAE				
Isoëtes muricata?				x
JUNCACEAE				
Juncus alpinus		x		
J. articulatus?		x		
LEGUMINOSAE				
Astragalus alpinus subsp. *alpinus*		x	x	x
Lupinus arcticus			x	x
Trifolium hybridum	x			
LEMNACEAE				
Lemna minor				x
LENTIBULARIACEAE				
Utricularia vulgaris			x	x
LILIACEAE				
Zygadenus elegans		x	x	x
LYCOPODIACEAE				
Lycopodium annotinum subsp. *annotinum*			x	
L. complanatum		x	x	x

	BIRCH LAKE	QUARTZ LAKE	HEALY LAKE	LAKE GEORGE
NYMPHAEACAE				
Nuphar polysepalum	x	x		x
ONAGRACEAE				
Epilobium adenocaulon				x
E. angustifolium		x	x	x
subsp. angustifolium	x			
E. palustre		x		
OPHIOGLOSSACEAE				
Botrychium lunaria			x	
ORCHIDACEAE				
Corallorrhiza trifida			x	
Cypripedium guttatum			x	
subsp. guttatum			x	
C. passerinum			x	
Goodyera repens var. ophioides		x		x
Platanthera obtusata			x	
Spiranthes romanzoffiana				x
OROBANCHACEAE				
Boschniakia rossica		x		
PINACEAE				
Larix laricina var. alaskensis	x			x
Picea glauca	x	x	x	x
P. mariana	x	x	x	x
PLANTAGINACEAE				
Plantago major	x	x		
POLEMONIACEAE				
Polemonium acutiflorum				x
POLYGONACEAE				
Polygonum alaskanum		x	x	x
P. amphibium		x		x
P. lapathifolium				x
POTAMOGETONACEAE				
Potamogeton epihydrus var. ramosus		x		
P. filiformis		x		x
P. gramineus?	x			
P. natans				x
P. perfoliatus subsp. Richardsonii	x	x	x	x

	BIRCH LAKE	QUARTZ LAKE	HEALY LAKE	LAKE GEORGE
POTAMOGETONACEAE				
Potamogeton robbinsii		x	x	
P. vaginatus				x
P. zosterifolius subsp. zosteriformis		x	x	x
PRIMULACEAE				
Androsace septentrionalis	x	x	x	x
PYROLACEAE				
Moneses uniflora		x	x	
Pyrola asarifolia			x	
P. chlorantha			x	
P. grandiflora	x			
P. secunda	x	x	x	x
subsp. obtusata			x	
RANUNCULACEAE				
Aconitum delphinifolium subsp. delphinifolium			x	x
Actaea rubra subsp. rubra			x	
Delphinium glaucum	x	x	x	x
Ranunculus glaucum			x	
R. gmelini	x			x
R. lapponicus	x			
R. macounii				x
R. reptans				x
R. trichophyllus				x
ROSACEAE				
Amelanchier alnifolia			x	
Fragaria virginiana subsp. glauca			x	
Geum macrophyllum subsp. perincisum	x	x	x	x
Potentilla fruticosa	x	x		x
P. norvegica subsp. monspeliensis			x	x
P. palustris	x	x	x	x
Rosa acicularis	x	x	x	x
Rubus arcticus subsp. acaulis	x		x	x
R. chamaemoris	x	x	x	x
R. idaeus subsp. melanolasius		x	x	x
Spiraea beauverdiana	x		x	x
RUBIACEAE				
Galium boreale	x	x	x	x
G. trifidum subsp. trifidum		x		x

	BIRCH LAKE	QUARTZ LAKE	HEALY LAKE	LAKE GEORGE
SALICACEAE				
Populus balsamifera	x	x	x	x
P. tremuloides	x	x	x	x
Salix bebbiana	x	x	x	x
S. glauca		x	x	x
S. alaxensis				x
Salix spp. (other)	x	x	x	x
SANTALACEAE				
Geocaulon lividum	x	x	x	x
SAXIFRAGACEAE				
Chrysoplenium tetrandrum	x	x	x	x
Parnassia palustris subsp. neogaea		x		
Ribes hudsonianum	x	x	x	
R. triste		x	x	x
Saxifraga reflexa			x	x
S. tricuspidata			x	x
SCROPHULARIACEAE				
Castilleja caudata			x	x
C. elegans			x	x
SELAGINELLACEAE				
Selaginella sibirica				x
SPARGANIACEAE				
Sparganium angustifolium				x
S. minimum		x		
UMBELLIFERAE				
Cicuta mackenzieana				x
Cnidium cnidiifolium		x	x	x
URTICACEAE				
Urtica gracilis			x	
VALERIANACEAE				
Valeriana capitata		x		

APPENDIX B

LABORATORY PROCEDURE FOR PROCESSING POLLEN SAMPLES

1. Carefully subsample core section at selected measured intervals to obtain a 1 cc subsample. Place sample in a 15 ml graduated centrifuge tube, here designated tube A.

2. If the core is to be analyzed to determine Absolute Pollen Influx, add a "spike" of 1 or 5 <u>Lycopodium</u> tablets. Record number of tablets added.

3. Add about 5 ml of NaOH to centrifuge tube; mix well; place tube in rack in boiling water bath for 30 minutes.

4. Remove tubes from waterbath, centrifuge at moderate speed for 5 minutes. Decant NaOH.

5. Rinse sample with about 10 ml of distilled water; stir vigorously, then centrifuge; decant distilled water.

6. Wash sample with about 8 ml of glacial acetic acid; centrifuge; decant (this step removes water).

7. Repeat step 6.

8. Add acetolysis mixture (9 parts acetic anhydride, 1 part H_2SO_4); mix with stirring rod; leave stirring rods in tubes; place tube rack in boiling water bath for 5 minutes. (Longer acetolysis time can be used if <u>Lycopodium</u> tablets are not being used.)

9. Remove from water bath; centrifuge well, and pour off carefully. (Acetolysis mixture reacts violently with water.)

10. Wash sample with glacial acetic acid; decant liquid.

11. Repeat step 10.

12. Rinse sample with distilled water; centrifuge; decant liquid.

Note: If <u>abundant</u> clays and other inorganic particles remain, sample may require additional treatment as follows:

A. Transfer sample to polypropylene tube.

B. Slowly add HCl. If carbonates may be present, begin with dilute HCl, stirring until foaming ceases; then add concentrated HCl. Otherwise use concentrated HCl only. Centrifuge; decant.

C. Add HF to tubes; carefully place tubes in boiling water bath for 1 hour. Note: this step and steps D & E must be performed under a functional fume hood. Wear lab apron, rubber gloves, and safety glasses or face shield. Avoid any contact with HF. Do not breathe fumes.

D. Remove tubes from water bath, fill tubes with 7% HCl; centrifuge; siphon off liquid.

E. Rinse sample with distilled water; centrifuge; siphon off liquid; wash residue back into original glass tube with distilled water.

F. If residue is sufficiently clean, mount on slide (See step 24); if inorganic particles remain, proceed with bromoform separation (Beginning with step 13).

13. Repeat step 12 (Distilled water rinse).

14. Rinse sample with acetone; centrifuge; decant.

15. Repeat step 14 twice to remove all traces of water.

16. Add 3 ml of bromoform-acetone mixture (adjusted to a specific gravity of 2.0); stir well; centrifuge.

17. Pour off heavy liquid (which now contains pollen and spores in suspension) into a clean centrifuge tube, here designated tube B.

18. Repeat steps 16 and 17, so that the samples have been treated twice for heavy liquid separation; tube B should contain 6 ml of heavy liquid.

19. Stir contents of tube B; add, if necessary, small amounts of bromoform-acetone mixture to bring all tubes to same level (to balance centrifuge); centrifuge.

20. Decant liquid containing pollen into a clean centrifuge tube (Tube C) containing 9.5 ml of acetone. This will alter the specific gravity of the fluid sufficiently to permit the pollen and spores to settle. Discard tube B.

21. Centrifuge tube C well; pour off liquid into bottle to save it for reclaiming costly bromoform.

22. Wash tube C pollen residue with acetone 2 or 3 times to remove all traces of bromoform.

23. Wash residue with distilled water to remove acetone; centrifuge; decant water carefully or siphon off; drain tube on paper towel to remove most remaining water.

24. Remove pollen residue with disposable pipette; mount residue on precleaned microscope slide.

25. Allow most of the water to evaporate from glass slide, but do not allow pollen to dry out completely.

26. Add one drop of glycerine (glycerol) which has been lightly stained with safranin.

27. Stir carefully with <u>clean</u> dissecting needle to distribute pollen and spores as evenly as possible in glycerine.

28. Carefully place clean cover slip onto drop of glycerine and allow glycerine to spread to fill the entire area under cover slip.

29. Attach label with sample locality, core number, and sample depth.

30. Store slides in horizontal trays or standard slide box kept in vertical position.

APPENDIX C

PREPARATION OF MODERN POLLEN REFERENCE MATERIAL

Collecting Samples:

Select large buds, flowers or stamens from dried specimens and store in small (app. 4 x 6) envelopes, well sealed. Record genus, species, author, family, collector, locality and herbarium on envelope. When ready to process, mark with date, number of tube into which pollen will be put and your identification number.

Processing Samples:

1. Cut off end of envelope, empty contents into wire mesh in funnel over centrifuge tube. With glass stirring rod, break up material to force pollen through mesh. Keep other tubes upside down so they do not get contaminated. Use a clean mesh, funnel and rod for each sample.

2. Make acetolysis mixture just before using. Put 9 parts acetic anhydride into a beaker, and <u>very slowly</u> add 1 part concentrated H_2SO_4, stirring carefully. Pour about 5-6 ml into each tube, pouring through wire mesh and funnel to wash pollen into tube.

3. When all tubes are ready, put rack into boiling water bath and boil till acetolysis mixture turns very dark brown and thick (test by dipping clean rod into one tube). This may take up to 1 hour.

4. Let cool about 15 minutes. Centrifuge and carefully pour off acetolysis mixture into waste beaker. Dispose of this in hood, pouring down drain slowly with running water.

5. Add glacial acetic acid, stir, centrifuge and pour off.

6. Repeat this step.

7. Add distilled water, stir, and centrifuge; pour off.

8. Repeat, this time pour off through clean wire mesh over a clean tube. Rinse out old tube, and pour mixture back, again through mesh. Centrifuge and pour off. (This step may be omitted if original sample was just anthers.)

9. Add 5% KOH, stir, centrifuge, and pour off.

10. Add 3:1 water and ETOH, stir, centrifuge, pour off, and stand tubes upside down in rack with paper towel in bottom.

11. Add 50% glycerine, stir well, let stand app. 1 hour, covered with paper towel.

12. Centrifuge well, pour off glycerine. Put tubes upside down in rack with paper towel in bottom.

13. Let stand in oven at 50° C overnight to dry.

Making Reference Slides:

1. With forceps, place piece of glycerine jelly on slide and cut into very small bits with razor blade.

2. Using clean needle, pick up bit of jelly, insert into tube, and pick up pollen from bottom of tube. Place glycerine on clean slide.

3. Place slide on hot plate until jelly melts (app. 225° F).

4. Stir material very gently, place cover glass over glycerine.

5. Put small piece of paraffin at the edge of cover slip, allow to melt and spread underneath.

6. Place slide aside to dry.

7. When dry, scrape off excess paraffin with razor blade, dip slide quickly into xylene and wipe clean with soft, lint-free cloth.

APPENDIX D

SEDIMENT ANALYSIS DATA*

*Sediment data is expressed as percent of total dry sample weight after removal of organics. Percent organics is calculated on the basis of the original dry sample weight (prior to removal of organics).

Birch Lake Core I

Core Interval		Grain-size intervals												
Core Interval		>0Ø	0Ø	1Ø	2Ø	3Ø	4Ø	5Ø	6Ø	7Ø	8Ø	9Ø	<9Ø	Organics
0-10	cm	0	0.2	0.5	0.3	1.5	9.3	23.8	27.3	21.2	5.3	3.1	7.6	3.5%
20-28	cm	0	0	0	0.4	2.5	9.1	23.7	22.0	19.3	9.6	2.6	10.7	2.8%
43-53	cm	0	0.1	0	0.1	2.4	7.5	23.4	23.4	22.0	9.4	3.6	8.1	3.1%
65-75	cm	0	0	0.1	0.2	1.3	3.7	20.8	25.6	26.0	11.4	3.3	7.6	2.8%
94-104	cm	0	0.1	0	0.1	1.2	3.1	20.1	21.0	25.8	16.2	2.4	10.0	2.7%
133-143	cm	0	0.2	0.2	1.1	1.6	5.1	17.9	27.6	26.2	8.7	4.1	7.4	3.1%
159-169	cm	0	0	0	0	0.8	3.4	12.5	16.3	23.4	10.5	13.4	19.6	1.6%
186-196	cm	0	0.1	0.1	0.2	1.0	4.1	16.0	28.8	32.6	5.7	3.8	7.9	3.4%
234-244	cm	0.1	0.5	0.1	0.1	0.7	3.8	17.1	30.3	19.9	13.3	6.6	7.6	2.0%
254-264	cm	0.1	0.1	0.2	0.2	0.7	4.1	8.5	37.9	19.4	11.4	5.7	11.8	2.5%
270-280	cm	0	0.1	0.1	0.2	0.7	3.5	15.3	32.0	22.4	12.4	2.9	10.5	2.5%

APPENDIX D

SEDIMENT ANALYSIS DATA*

*Sediment data is expressed as percent of total dry sample weight after removal of organics. Percent organics is calculated on the basis of the original dry sample weight (prior to removal of organics).

<u>Birch Lake Core II</u> Grain-size intervals

Core Interval	>0Ø	0Ø	1Ø	2Ø	3Ø	4Ø	5Ø	6Ø	7Ø	8Ø	9Ø	<9Ø	Organics
0-20 cm	0	0	0	0	0	0	28.0	34.0	17.0	5.0	7.0	9.0	5.7%
80-96 cm	0	0	0	0	0	0	37.5	13.0	27.5	8.0	0.5	13.5	10.5%
95-110 cm	0	0	0	0	0	0	20.5	36.5	12.0	9.5	6.0	16.5	17.1%
150-165 cm	0	0	0	0	0.1	0.8	51.5	11.4	9.9	9.4	6.0	10.9	no data
200-215 cm	0	0	0	0	0	0	31.0	22.5	18.0	12.0	6.5	10.0	13.7%
270-280 cm	0	0	0	0	0	0	36.0	19.5	22.5	13.5	1.5	7.0	8.2%
310-320 cm	0	0	0	0	0	0	54.0	18.5	20.5	4.5	0	2.5	3.2%
320-330 cm	0	0	0	0	0	0	29.0	36.5	13.0	2.0	2.5	17.0	9.0%
375-395 cm	0	0	0	0	0	0	25.0	43.0	25.0	2.0	3.0	2.0	3.0%
400-415 cm	0	0	0	0	0	0	14.0	31.0	27.5	14.5	9.0	4.0	2.0%
487-500 cm	0	0	0	0	0	0	10.5	39.5	37.0	10.0	0.5	2.5	2.5%
540-550 cm	0	0	0	0	0	0	27.0	53.0	16.7	0.3	0.3	2.7	2.1%
570-580 cm	0	0	0	0	0	0	50.5	39.5	10.0	TR	0	TR	1.2%
587-596 cm	0	0	0	0	0.2	1.0	51.0	27.2	3.3	2.0	0	15.3	0.6%
600-610 cm	10.1	4.7	2.8	1.8	1.9	4.3	42.4	14.7	7.9	0	0	9.4	0%
610-620 cm	21.8	5.3	3.2	2.3	2.5	6.4	43.5	8.5	Tr	0	0	6.4	1.1%

APPENDIX D

SEDIMENT ANALYSIS DATA*

*Sediment data is expressed as percent of total dry sample weight after removal of organics. No data is available for the organic content of the samples.

<u>Healy Lake Core I</u>		Grain-size intervals								
Core Interval	1Ø	2Ø	3Ø	4Ø	5Ø	6Ø	7Ø	8Ø	9Ø	<9Ø
30-40 cm	0.1	0.2	0.8	4.8	31.1	18.8	18.4	9.4	5.2	11.3%
85-95 cm	0	0.2	0.6	3.9	11.4	27.6	25.7	12.8	6.7	10.9%
118-128 cm	0	0.3	1.6	9.4	31.9	15.1	16.8	9.7	5.3	9.7%
170-180 cm	0	0.3	3.4	20.2	19.8	31.6	14.1	4.6	1.4	4.6%
200-210 cm	0.1	0.2	2.5	18.6	22.8	22.1	14.2	7.9	4.3	7.5%

APPENDIX D

SEDIMENT ANALYSIS DATA*

*Sediment data is expressed as percent of total dry sample weight after removal of organics. Percent organics is calculated on the basis of the original dry sample weight (prior to removal of organics).

<u>Lake George Core I</u> — Grain-size intervals

Core Interval		>0Ø	0Ø	1Ø	2Ø	3Ø	4Ø	5Ø	6Ø	7Ø	8Ø	9Ø	<9Ø	Organics
0-30	cm	0	0	0	0	0.1	2.0	33.7	8.3	19.1	10.3	8.8	17.7	9.3%
30-45	cm	0	0	0	0	0.2	1.4	24.2	16.7	18.6	18.6	9.8	9.6	no data
100-120	cm	0	0	0	0	0.1	1.9	33.8	15.7	13.2	10.8	8.8	15.7	9.1%
130-140	cm	0	0	0	0	0.4	1.9	35.7	12.4	15.6	12.8	7.8	13.6	no data
197-222	cm	0	0	0	0	0.2	1.8	38.2	13.2	11.3	7.8	10.8	16.7	5.4%
227-247	cm	0	0	0	0	0.2	1.4	33.3	12.0	18.5	11.6	7.9	15.1	no data
335-360	cm	0	0	0	0	0	3.2	30.2	16.8	15.1	10.0	5.0	19.7	no data
360-381	cm	0	0	0	0	0.2	2.0	25.4	10.8	13.2	13.7	10.8	23.9	8.1%
427-447	cm	0	0	0	0	0.3	1.5	28.8	11.4	13.6	11.9	6.8	25.7	no data
447-465	cm	0	0	0	0	0.1	1.4	27.1	8.4	12.3	1.5	13.8	35.5	6.7%
477-497	cm	0	0	0	0	0.5	2.5	48.5	9.7	6.8	9.7	8.7	13.6	5.1%
487-507	cm	0	0	0	0	1.7	2.6	39.8	4.9	14.8	8.5	9.0	18.8	no data
531-551	cm	0	0.1	0.6	1.5	2.3	3.0	35.1	14.8	13.9	8.3	7.4	13.0	6.4%
736-756	cm	TR	0.1	0.2	0.2	0.5	1.8	9.2	13.1	24.3	18.9	18.0	14.0	no data

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